Cover Page

EVALUATION OF SILICA-BASED DUSTS FOR THE MANAGEMENT OF RED FLOUR BEETLE (*Triboliumcastaneum*Herbst) INFESTING STORED WHEAT GRAINS

By

JUMMAI ABDULFATAI IBRAHIM

DEPARTMENT OF CROP PROTECTION,
FACULTY OF AGRICULTURE,
AHMADU BELLO UNIVERSITY, ZARIA
NIGERIA

JUNE, 2017

Title Page

EVALUATION OF SILICA-BASED DUSTS FOR THE MANAGEMENT OF RED FLOUR BEETLE (*Triboliumcastaneum*Herbst.) INFESTING STORED WHEAT GRAINS

By

JummaiAbdulfatai IBRAHIM

B.AGRIC (UNIMAID) 2010

M.Sc/AGRIC/25710/2012-2013

ADISSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIAIN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER DEGREE IN CROP PROTECTION

DEPARTMENT OF CROP PROTECTION,
FACULTY OF AGRICULTURE,
AHMADU BELLO UNIVERSITY, ZARIA,
NIGERIA

JUNE, 2017

Declaration

I declare that the work in this dissertation entitled "Evaluation of Silica-Based Dusts for the Management of Red Flour Beetle (*Triboliumcastaneum*Herbst.) Infesting Stored Wheat Grains" has been carried out by me in the Department of Crop Protection, Faculty of Agriculture, Ahmadu Bello University, Zaria. The information derived from literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another Degree or Diploma at this or any other Institution.

JummaiAbdulfataiIBRAHIM
Name of Student

Date

Certification

This dissertation entitled "EVALUATION OF SILICA-BASED DUSTS FOR THE MANAGEMENT OF RED FLOUR BEETLE (*Triboliumcastaneum*Herbst.) INFESTING STORED WHEAT GRAINS" by JummaiAbdulfataiIBRAHIM meets the regulations governing the award of the degree of Master of Science (M.Sc.) in Crop Protection of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

__________________________ __________________
Prof.L.J. Bamaiyi Date
Chairman, Supervisory Committee

__________________________ __________________
Prof. A.M. Oparaeke Date
Member, Supervisory Committee

__________________________ __________________
Prof. I. Onu Date
Member, Supervisory Committee

__________________________ __________________
Prof.O.O. Banwo Date
Head of Department

__________________________ __________________
Prof.S.Z. Abubakar Date
Dean, School of Postgraduate Studies

Dedication

This work is dedicated to Almighty Allah (SWT), His beloved Prophet Muhammad (SAW), my loving and caring husband, Engr. Dr. Abdulfatai Adinoyi Murana, my dearest parent, Mr and Mrs. Ibrahim Siyaka and finally to my lovely children, NazeeyaInyaoiza, NimatullahOyiza and Nana-AishahAhuoiza.

Acknowledgements

All praise is due to Allah, the Beneficent, and the Merciful Who remains the seal of knowledge. I am most thankful to Him for sparing my life and leading the course of this endeavour.

The presentation of this dissertation has become possible due to the guidance of the following people whose assistance and direction I very much appreciate and therefore acknowledged.

Foremost I will like to appreciate the Chairman, supervisory committee, Prof.L.J. Bamaiyi, who was the principal propelling force urging me on till the work was completed. Profs. A.M. Oparaeke and I. Onu, (members of supervisory committee) also contributed in no small measure to the eventual completion of this dissertation and their wonderful assistance during the development of this research and its successful completion.

I am indebted to my loving and caring husband, Engr. Dr. Abdulfatai Adinoyi Murana, my parent Mr. and Mrs. Siyaka Ibrahim, my lovely children, NazeeyaInyaoiza, NimatullahOyiza and Nana-AishahAhuoiza and brothers and sisters for supporting me throughout this program.

I am also indebted to Prof.O.O. Banwo, Head of Department Mr livinusBawa, Late HajiyaMaimunaOmeiza and other members of staff of theDepartment of Crop Protection, Ahmadu Bello University, Zaria who in one way or the other contributed to the success of this dissertation.

Abstract

Laboratory studies were conducted in the Entomology Laboratory of Crop Protection Department, Institute for Agricultural Research, Ahmadu Bello University, Samaru-Zaria, to evaluate the efficacies of four silica-based dust namely; Diatomaceous earth (DE), Periwinkle shell dust (PSD), Rice husk ash (RHAC), and Prawn shellash (PSA) with Pirimiphos methyl (Actellic EC) as the standard check and untreated control (which had no treatment at all) for the management of *Triboliumcastaneum*(Herbst) on stored wheat. The treatments were laid out in a completely randomized design (CRD) at five concentrations (0.25, 0.50, 1.00, 1.50 and 2.00g/100g of wheat grains) each repeated three times. The parameters assessed for the efficacy of the silica based dust include; adult mortality at 24, 48 and 72 hours post treatment; progeny emergence (F_1 and F_2), and percentage grain damage. Results obtained sowed that DE applied at 1.00and 2.00 g/100 g had hundred percent mortality. PSA had 93 % adult insect mortality, which was not significant difference from the standard check (Actellic EC).RHC and PS together with the untreated check had the least number of adult insect mortalityand were not significantly different. F_1 and F_2 progeny emergence was inhibited in all the treatments except the untreated check. At 40 days post-treatment (F_1) progeny emergence was completely (100%) suppressed by the standard check followed by PSD (0.33), DE (1.00), RHAC (1.47) and PS had the least control of progeny (6.13). At 80 days, F_2 progeny emergence showed that RHC had least mean number of emergence (0.067), followed by DE (0.20), PSD (1.33) and PS (5.33). There was no significant difference between PSD, DE and RHAC with the standard check in terms of preventing grain damage. PSD, DE and RHAC treated wheat grains had the least grain damage which were similar to the standard check. Wheat grains treated with PS suffered the highest grain damage which was similar to the untreated check. DE was the best among the silica-based dust followed by PSD, then RHAC in the control of *T.castaneum*, while PS had the least control. Therefore, DE, PSD and RHAC can be recommended for use as grain protectant.

Table of Contents

List of Tables

List of Plates

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background Information

Wheat *(Triticum*spp.) is a cereal grain, originally from the Levant region of the Near East and Ethiopian Highlands, but now cultivated worldwide. Wheat belongs to the grass family *Poaceae*(Belderok *et al*., 2000). In 2014, world production of wheat was 713 million tons, making it the third most-produced cereal after maize (1,016 million tons) and rice (745 million tons)while for that of Nigeria, wheat production quantity was 90, 000 tonnes(FAOSTAT, 2015). Wheat has been cultivated in Nigeria for several centuries especially, in the Northern States in the hydromorphic lowlands or valleys and watercourse in the relatively colder areas. However, large scale production to meet local demands for bread, cakes and other confectionaries commenced after the development of irrigation schemes in 1959 at Wurno, Hadejia, and GamboruNgala(Mustapha, 1998). Wheat production in Nigeria is mainly in the Sudan and Sahel ecological zones, which include the Chad Basin, HadejiaJama'are River Basin and Sokoto Rima Basin. The crop is cultivated under irrigation during the cold "Harmattan" period between the months of November and February which provides the required low night temperatures ranging from 10 to 25^{0}C (Abbas, 1988).

Wheat demand is very high in Nigeria as a result of increasing population and urbanization and large proportion of the demand is met through importation (Aminu-Kano and Ikwelle, 1998). Efforts to satisfy local consumption through domestic production have failed because of many technical and political problems (Mustapha, 1998).In order to boost food production in the country, the government in 1976 promulgated a decree establishing 11 River Basin Development Authorities (Olugbemi, 1990). Three of these are; the Hadejia-Jama'are Basin (Kano/ Jigawa States), the Sokoto-Rima Basin (Sokoto, Zamfara and Kebbi States), and the Chad Basin (Borno/Yobe States), which are located within latitudes 10-14°N to promote wheat production. When fully developed, the three river basins were to provide about 345,000 ha of irrigated land with about 50-60% of it allocated to wheat.

Wheat is planted to a limited extent as a forage crop for livestock, and its straw can be used as a construction material for roofing thatch (Smith, 1995). The whole grain can be milled to leave just the endosperm for white flour. The by-products of this are bran and germ. The whole grain is a concentrated source of vitamins, minerals, and protein, while the refined grain is mostly starch.Wheat is used as a food plant by the larvae of some Lepidoptera (butterfly and moth) species including the Flame*Anisancanthusguadrifidus*, Rustic Shoulder-knot*Apameasordens*, Setaceous Hebrew Character*Xestia c-nigrum* and Turnip Moth*Agrotissegetum*. Early in the season, many species of birds, including the Long-tailed Widowbird*Euplectesprogne*, and rodents feed upon wheat crops. These animals can cause significant damage to a crop by digging up and eating newly planted seeds or young plants. They can also damage the crop late in the season by eating the grain from the mature spike. Recent post-harvest losses in cereals amount to billions of dollars per year in the USA alone, and damage to wheat by various borers, beetles and weevils is no exception. Rodents can also cause major losses during storage, and in major grain growing regions, field mice numbers can sometimes build up explosively to plague proportions because of the ready availability of food(Anonymous, 1990).

1.2 Justification ofthe Study

Dry wheat grain is damaged by many insect pests, some of which are field to store pests. Pests such as insects, rodents and mites are the cause of most damages to grains.

The important storage pests of wheat are*Sitophilus*spp., *Oryzaephilussurinamensis*, *Triboliumcastaneum* (Herbst.), *Rhyzoperthadominica* (F.)*Triboliumconfusum* (Duval.)(Stathers *et al*., 2004). Although*Triboliumcastaneum*hasbeenconsidered to be a secondary pest, its control should not be ignored. This isbecause it has been found to attack groundnut kernels and pods(Paulraj and Shayaraj, 2002). *T. castaneum* could cause damage to whole maize meant for planting thus assuming a primary pest status(IITA, 2011).*T. castaneum*has long been associated witha wide range of commodities including grains (wheat, peas, beans, flour, nuts, dried fruits and spices). This insect causes a substantial loss to these produce in storage because of its high reproductive potential (Bekele *et al*., 1997).

It is therefore of paramount importanceto control the attack by the insectpests if food security and sufficiency is to be achieved. Thecontrol of these pests has been mainly through the use ofconventional chemicals. The use of conventional dusts (e.g.pirimiphos – methyl, permethrin) and fumigants (e.g.aluminium phosphide) and their effectiveness against *Callosobrunchusmaculatus* in storage has been reported by Jackai and Daoust(1986). The control of storage insects like *Sitophiluszeamais*has centredmainly on the use of synthetic insecticides(Asawalam *et al*., 2007). The most popular practice in protecting stored seedsagainst insect pest damage is the use of synthetic cropprotection agents(Subramanyam and Hagstrum, 1995; Ofuya, 2003; Adebayo and Ibikunle, 2014).

The major setbacks to the use of synthetic pesticides include itsrisk to the user, high cost of procurement, development ofresistant species and residue in the food crops. The aforementioned have led scientists to investigate plantproducts as alternative to synthetic pesticides(Lale, 2002). Whenthe insecticides are used improperly they pose risk to man and theenvironment, a risk that is most common among uneducated rural farmers in Africa(Ofuya, 2003). Insecticides derived fromplants and other biological materials could be betterreplacement for synthetic insecticides in stored productsprotection(Lale, 2001). Plant products such as vegetable oils, essential oils, crude extracts and powders have been testedagainst *C. maculatus.* (Golob *et al*., 1991; Lale, 1995; Dales, 1996; Boeke *et al*., 2001). Powder of many indigenous plants when applied at 2% of the weight of stored beans effectively controlled cowpea seed beetle during storage(Lale, 1994; Ogunwolu and Odunlami, 1996; Adedire and Lajide, 2001; Adebayo and Ibikunle, 2014).

Therefore this study tried to investigate the potentials ofdiatomaceous earth (DE), Periwinkle shell dust (PSD), Rice husk concentrate (RHC), and Prawn shellash (PSA) as grainprotectants against *T.castaneum*.

Diatomaceous Earth (DE) is a natural product of soft rock that is fossilized remains of unicellular algae called diatoms (Koranic, 1998). Rice husk is one of the most widely available agricultural wastes in many rice producing countries of the world. Rice hulls (or rice husks) are the hard protecting coverings of grains of rice and are removed from rice grain as a by-product during the milling process. The common periwinkle or winkle *(Littorinalittorea*) is a species of small edible sea snail, a marine gastropod mollusc that has gills and an operculum, and is classified within the family littorinidae, the periwinkle. Prawn is a common name, which originated from the United Kingdom, Ireland and Commonwealth nations, for large swimming crustaceans or shrimp, especially those with commercial significance in the sea food industry(Reid and Gofas, 2011).

1.3 Aim and Objectives of the Study

The aim of the research is to assess the efficacyof Silica-based dust against *T.castaneun* infesting stored wheat grain. This aim was achieved with the following objectives:

1. To evaluate the effect of Silica-based dusts on adult mortality andprogeny development of *T.castaneum*.
2. To evaluate the effect of Silica-based dusts ongrain damage by *T.castaneum*.
3. Effect of Silica-based dusts rate on adult mortality and progeny development.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Importance of Wheat Grain

Wheat is a cereal crop belonging to the grass family *Poaceae*(Subramanyam and Hagstrum, 1995). Major cultivated species of wheat are; Hexaploides, Tetreploid and diploid species. The hexaploides species is the most widely cultivated in the world for example common wheat or bread wheat (*Triticumaestivum* and *Triticumspelta*). The only tetraploides form of wheat widely used today and the second most cultivated wheat is durum species (*Triticum durum*). Emmer was also a type of tetraploid species cultivated in ancient time, while the diploid species has a wild and cultivated variants e.g.Einkom species (*T.monococcum*). Common wheat accounts for approximately 95% of world production, the remaining 5% of the cultivated varieties are, Durum wheat which is tetraploid species used for producing pasta and couscous (Hill*et al*., 1995).

Wheat normally needs between 110 and 130 days between sowing and harvest, depending upon climate, seed type, and soil conditions (winter wheat lies dormant during a winter freeze). Optimal crop management requires that the farmer has a detailed understanding of each stage of development in the growing plants. In particular, fertilizers, herbicides, fungicides, and growth regulators are typically applied only at specific stages of plant development. For example, it is currently recommended that the second application of nitrogen is best done when the ear (not visible at this stage) is about 1 cm in size. Knowledge of stages is also important to identify periods of higher risk from the climate. For example, pollen formation from the mother cell and the stages between anthesis and maturity are susceptible to high temperatures, and this adverse effect is made worse by water stress. Farmers also benefit from knowing when the ‘flag leaf (last leaf) appears, as this leaf represents about 75% of photosynthesis reactions during the grain filling period, and so should be preserved from disease or insect attacks to ensure a good yield(Slafer and Satorre, 1999).

Wheat cultivars are further classified by wheat breeders and farmers in terms of: Growing season, such as winter wheat vs. spring wheat. Although Nigeria is a major market for hard red wheat (HRW), in recent years there has been a steady increase in demand for other types of wheat such as Soft Red Winter wheat (SRW) for use in cookies (biscuit) production, Hard White Wheat (HWW) for bread and noodle production. Wheat grain is a staple food used to make flour for leavened, flat and steamed breads, biscuits, cookies, cakes, breakfast cereal, pasta, noodles, couscous, for fermentation to make beer and other alcoholic beverages or biofuel (Cauvain and Cauvain, 2003; Palmer, 2001).

Protein content- Bread wheat protein content ranges from 10% in some soft wheat with high starch contents, to 15% in hard wheat. This quality of the wheat gluten protein; can determine the suitability of wheat to a particular dish. Strong and elastic gluten present in bread wheat enables dough to trap carbon dioxide during leavening, but elastic gluten interferes with the rolling of pasta into thin sheets. The gluten protein in durum wheat used for pasta is strong but not elastic. Many wheat varieties are reddish-brown due to phenolic compounds present in the bran layer, which are transformed to pigments by browning enzymes. White wheat has a lower content of phenolic and browning enzymes, and is generally less astringent in taste than red wheat. The yellowish colour of durum wheat and semolina flour made from it is due to a carotenoid pigment called lutein, which can be oxidized to a colourless form by enzymes present in the grain(Cauvain and Cauvain, 2003).

Durum wheat is very hard, translucent, and light-coloured grain used to make semolina flour for pasta and bulghur; high in protein, specifically, gluten protein. Hard red spring wheat is hard, brownish and high-protein; used for bread and hard baked goods. Bread flour and high-gluten flours are commonly made from hard red spring wheat. Hard red winter wheat is hard, brownish and mellow high-protein used for bread, hard baked goods and as an adjunct in other flours to increase protein in pastry flour for pie crusts (Cauvain and Cauvain, 2003).Some brands of unbleached all-purpose flours are commonly made from hard red winter wheat alone.

Soft Red Winter wheat is soft, light-coloured, low-protein wheat used for cakes, pie crusts, biscuits, and muffins. Cake flour, pastry flour, and some self-rising flours with baking powder and salt added, for example, are made from soft red winter wheat. Hard White wheat is hard, light-coloured, opaque, chalky, medium-protein wheat planted in dry temperate areas and used for bread and brewing. Soft White wheat is soft, light-coloured, very low protein wheat grown in temperate moist areas and used for pie crusts and pastry. Pastry flour, for example, is sometimes made from soft white winter wheat. Red wheat may need bleaching; therefore, white wheat usually command higher prices than red wheat on the commodities market.

Raw wheat can be ground into flour or, using hard durum wheat only, can be grounded into semolina; germinated and dried creating malt; crushed or cut into cracked wheat; parboiled (or steamed), dried, crushed and de-branded into bulgur also known as gloats. If the raw wheat is broken into parts at the mill, as is usually done, the outer husk or bran can be used in several ways.

Wheat is a major ingredient in such foods as bread, porridge, crackers, biscuits, Muesli, pancakes, pies, pastries, cakes, cookies, muffins, rolls, doughnuts, gravy, boza (a fermented beverage), and breakfast cereals (e.g., Wheatena, Cream of Wheat, Shredded Wheat, and Wheaties). Much of the carbohydrate fraction of wheat is starch. Wheat starch is an important commercial product of wheat, but second in economic value to wheat gluten. The principal parts of wheat flour are gluten and starch. These can be separated in a kind of home experiment, by mixing flour and water to form a small ball of dough, and kneading it gently while rinsing it in a bowl of water. The starch falls out of the dough and sinks to the bottom of the bowl, leaving behind a ball of gluten(Palmer, 2001).

Plate I shows the picture of samples of wheat grains.

Plate I: Wheat Seed

2.2 Economic Importance of Stored Product Insect Pests

The number of insect species associated with stored wheat, sorghum, millet, rice and maize in Nigeria are 10, 8, 10, and 12 different pest species respectively (Lale and Ofuya, 2001). These are mainly the Coleopteran and Lepidopteraninsect’s pests. The most common storage pests however, are Coleopterans (Appert, 1987; Delima, 1987; Hill and Walker, 1990). In general, a total of 22 insect pests have been listed as important in Nigeria (Lale and Ofuya, 2001). Processed cereals and pulses are attacked mainly by secondary pests. Hill and Walker, (1990) argued that processing marketers produces wheat that is more susceptible to insect attack. However, milling also limited the range of pest species that attack wheat grains. The flour beetles (*Triboliumcastaneum*Herbst.) have been singled out as the major secondary pest of stored milled cereals flours and food production, the food processing industries(Hill and Walker, 1990). The damage caused by insects is losses of quality, contamination, weight loss, poor germination and spread of disease causing organisms.

2.3 Damage byRed Flour Beetle (*Triboliumcastaneum*)

*Triboliumcastaneum*is attracted to grains with high moisture content and can cause a grey tint to infested grains. The beetles give off a displeasing odour, and their presence encourages mould growth in grains. Red flour beetles attack stored grain products such as flour, cereals, meal, crackers, beans, spices, pasta, cake mix, dried pet food, dried flowers, chocolate, nuts, seeds, and even dried museum specimens. These beetles have chewing mouthparts, but do not bite. The red flour beetle may elicit an allergic response but is not known to spread disease and does not feed on or damage the structure of a home or furniture. These beetles are two of the most important pests of stored products in the home and grocery stores(Hill and Walker, 1990; Alanko *et al.*, 2000).

2.3.1 Life cycleof red flour beetle (*Triboliumcastaneum*)

The eggs are white, microscopic and often have bits of flour stuck to their surface. The slender larvae are creamy yellow to light brown in colour. They have two dark pointed projections on the last body segment. The pupae are lighter in colour, being white to yellowish. These beetles can breed throughout the year in warm areas. The life cycle takes from 40 to 90 days. All forms of the life cycle may be found in infested grain products at the same time.Plate II shows the life cycle of red flour beetle(Bousquet, 1990).

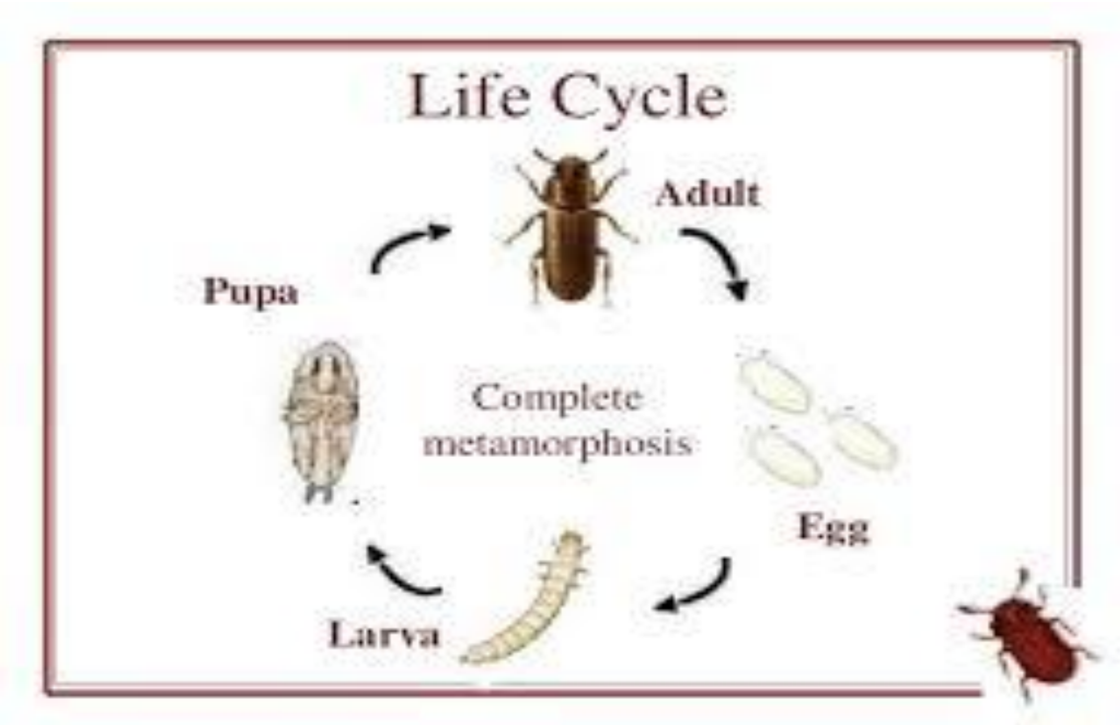

Plate II: Life cycle of Red Flour Beetle (*Triboliumcastaneum*) (Herbst)
Source: (Bousquet, 1990)

2.3.2 Origin and Description of *Triboliumcastaneum*

The red flour beetle is of Indo-Australian origin and is found in temperate areas, but will survive the winter in protected places, especially where there is central heat. In the United States, it is found primarily in the southern states. The confused flour beetle, is of African origin but occurs worldwide in both hotter and colder climates (Smith and Whitman, 1992).

The eggs are small, cylindrical and white. Larvae are yellowish white and about 6 mm long when fully grown. The head is pale brown and the last segment of the abdomen has an up-turned dark pointed structures. The pupae are yellowish white, later becoming brown. The dorsum is hairy and the tip of the abdomen has two spine-like processes. The adult is flat, oblong, reddish, brown or dark brown and about 3-4 mm long. The last three segments of the antenna are club shaped. The elytra have fine punctured lines. The male has a hairy puncture on the ventral surface of the anterior femur. The eyes of the adults are close ventrally. The larvae have two upward curved on the ninth abdominal segment(Amatobi, 2007).

Although small beetles, about 4.5mm long, the adults are long-lived and may live for more than three years.The red flour beetle is reddish-brown in colour and its antennae end in a three-segmented club. The head of the red flour beetle is visible from above, does not have a beak and the thorax has slightly curved sides. The insect belong to the family Tenebrionidae and have a tarsal formula of 5-5-4 and notched eyes(Anonymous, 1990; Bousquet, 1990).The red flour beetle may fly, especially before a storm.

2.3.3 Economic importance of *Triboliumcastaneum*

Triboliumcastaneum is considered a primary pest of stored product, which is classified as the most important of storage pest because when present in grains contributes to contamination and depreciation of commercial value of the flour of cereal. Both the adult and larvae feed on a variety of food products and grains in which they produce toxic quinones, which contaminate flour and flour products. Damage is specially done to broken grains or damaged grains(Athanassiou *et al*., 2003).

2.4 Differencebetween *Triboliumcastaneum* and *Triboliumconfusum*

Red and confused flour beetles(*T. castaneum T. confusum*) attack stored grain products such as flour, cereals, meal, crackers, beans, spices, pasta, cake mix, dried pet food, dried flowers, chocolate, nuts, seeds, and even dried museum specimens.The confused flour beetle apparently received this name due to confusion over its identity as it is so similar to the red flour beetle at first glance (Hill and Walker, 1990).

The red flour beetle is reddish-brown in colour and its antennae end in a three-segmented club, whereas the confused flour beetle is the same colour but its antennae end is gradually club-like, the “club” consisting of four segments. The head of the red flour beetle is visible from above, does not have a beak and the thorax has slightly curved sides. The confused flour beetle is similar, but the sides of the thorax are more parallel.These two beetles are in the family Tenebrionidae and have a tarsal formula of 5-5-4 and notched eyes(Anonymous, 1990; Bousquet, 1990; Hill and Walker, 1990).Plate III shows the picture of a red flour beetle (*T.castaneum*) while Plate IV shows the picture of a confused flour beetle(*T.confusum*).

PlateIII: Red Flour Beetle (*Triboliumcastaneum*) (Herbst)

PlateIV:Confused Flour Beetle (*Triboliumconfusum*) (Herbst)

The red and confused flour beetles live in the same environment and compete for resources. The red flour beetle may fly, especially before a storm, but the confused flour beetle does not fly. Eggs, larvae, and pupae from both species are very similar and are found in similar environments. All forms of the life cycle may be found in infested grain products at the same time.The adults are attracted to light, but will go towards cover when disturbed. Typically, these beetles can be found not only inside infested grain products, but in cracks and crevices where grain may have spilled. They are attracted to grain with high moisture content and can cause a grey tint to the grain they are infesting. The beetles give off a displeasing odour, and their presence encourages mould growth in grain(Hill and Walker, 1990).

2.5 Control of Stored Product Insects Pests

The first step in managing an infestation is to find and remove the source of the infestation (Koehler, 2003). Flour beetles can feed and survive on even the smallest bits of grain, so cleaning is a crucial part of controlling these pests. When attempting to locate the source, be sure to consider all likely food items including, dry pet food, dried flours, nuts, birdseed, and all grain products. Be sure to look for “leaky packages.” Small bits of meal or grain spilling from a package are often a signal that an infestation is present (Arbogast *et al.*, 2000). Be sure to locate all infested material and discard it by placing the material into a sealed bag or container and throwing it into an outside garbage container. You may also place the infested material into a freezer for four to five days because these beetles may survive freezer times shorter than this. The control of stored product pest infestation depends mostly on insecticides of broad spectrum action and fumigants. Combination of physical and biological methods can be integrated to increase efficiency in control of pests, and also to decrease the use of chemical products. The impact of beneficial species and cost, alternative control are beneficial and being emphasized so as to reduce the application of insecticides and decrease human exposure potentials and development of resistance. The use of inert dust to control grain pest is a long history and has been reviewed by many authors (Lashiavo, 1988; Shawir *et al.*, 1988; Aldryhim, 1990; Aldryhim, 1993). These reported problems associated with the use of chemical control of stored product insect, including low or high temperature, sanitation and biological control (Golob *et al.,* 1982; Fields, 1992).

2.5.1 Chemical control of stored product insects pests

Chemical control includes the use of insecticides to prevent or manage insect infestations. They have proved to be the simplest and most cost effective means of dealing with the pest. Even though synthetic chemicals continue to play important role in reducing storage loses due to insect pest activities, insecticides resistance, toxic residues in food and environmental pollution, adverse effect on beneficial and non-target insect, increases risk to workers safety, and the high cost of the chemicals makes them less attractive. Some common insecticides used against storage pest are; Carbon disulphides, Phostoxin, Pyrethrin, Permenthrin, Malathion, Diazinon, Sumthion, Actellic dust, Ethylene dibromide(Niber, 1994; Asawalam *et al*., 2006; Perez-mendoza, 1999).

2.5.2 Physical control of stored product insects pests

This storage method involves manipulation of the storage atmosphere (temperature, relative humidity, oxygen etc.). The environment may be altered to make it inimical to the pest. In small quantities of stored grains and at low infestation level; *Triboliumspp*can be removed physically by hand picking, relative humidity help in controlling insect population in stored products. The death of insects under a carbon-dioxides rich atmosphere is largely due to excessive loss of water from their bodies caused by prolonged opening of their spiracles(Niber, 1994; Asawalam *et al*., 2006; Perez-mendoza, 1999).

2.5.3 Biological control of stored product insects pests

This is the introduction or action of natural enemies (parasites, parasitoids, predators etc.) of pest to reduce pest population to a level where economic losses are not possible. Reptiles like lizard feed on most storage pest including *Tribolium* during drying process. The family *Pteromalidae* contain the most frequently encountered parasitic wasps in tropical storage. *Anisopteromaluscalandrae* (Howard.) has been identified as one of the biological control agent of a wide range of storage pests, including maize weevils, rice weevils, and the Angoumois grain moth(Niber, 1994; Asawalam *et al*., 2006; Perez-mendoza, 1999).

2.5.4 Host plant resistance to insect

This is the genetic property that enable plant to avoid, minimize, tolerate or recover from injury caused by insects. The use of resistant varieties is a very crucial and effective means of pest management requiring no use of chemical hazards and does not require sophisticated skill or training for the farmers before use, but only the cultivation of the resistant cultivars(Niber, 1994; Asawalam *et al*., 2006; Perez-mendoza, 1999).

2.6 Inert Dust Materials

Inert dusts are chemically unreactive dusts that have insecticidal capability, killing by physical rather than chemical means. Insects coated with these dusts are dehydrated and die. Because the effect is through desiccation, the effectiveness of inert dusts decreases as relative humidity increases. There is renewed interest in technology associated with use of inert dusts in grain storages and a number of reviews have been written (Banks and Fields, 1995; Golob, 1997; Subramanyam and Hagstrum, 2000; Mahdi and Khalequzzaman, 2006). Inert dusts have been used for centuries by aboriginal people in North America and Africa to control insects in their stored grain(Shadia, 2011).

There are five types of inert dusts(Fields and Muir, 1996). Sands and other soil components are traditional insecticides used by aboriginal peoples as a protective layer on top of stored seed(Golob and Webley, 1980).Diatomaceous earth, the fossilized remains of diatoms that are microscopic, unicellular, aquatic plants that have a fine shell made of opaline silica (SiO_2 + n H_2O). DE has extremely low toxicity to mammals (e.g., where DE toxicity for rat LD_{50} oral >5000 mg kg^{-1}) and are generally regarded as safe by the USA Environmental Protection Agency(Subramanyam and Hagstrum, 1995; Anonymous, 1991). Abd-El-Aziz and Sherief (2010) made chemical modification to the natural Diatomaceous Earth (DE) by different mono-, di-, tri-valent metal hydroxides (MOH, M = Na, Ca, Al) to increase its efficacy. The most effective DE modification was Ca.DE, which has insecticidal, repellent and ovicidal effects against *Callosobruchusmaculatus* and can be used effectively in stored grain integrated pest management program(Abd-El-Aziz and Sherief, 2010).

Silica aerogel, which is produced by drying an aqueous solution of sodium silicate, is a light powder that is not hygroscopic(Quarles, 1992).Non-silica dusts, such as rock phosphate, have been used in Egypt and lime (calcium oxide) provides some control of storage pests(Golob and Webley, 1980).Particle films (Kaolin and bentonite clays) or kaolinite-based particle films may also have potential for use as a dry dust material in stored-product environments, especially in specialty organic markets that prohibit the use of diatomaceous earth. Several studies were conducted to evaluate the potential of kaolinite-based particle films to control *T.castaneum*, the red flour beetle and *T.confusum*. These two beetle species are major pests inside milling and processing facilities, food warehouses and food plants. The particle film M-96-018 was effective against both the *Tribolium*species and appears to have a potential for use in management programmes to control beetles within storage facilities(Arthur and Puterka, 2002).The main advantage of using inert dusts is that they are non-toxic to humans and animals. Diatomaceous earths are registered as a food additive in the USA. Inert dusts in stored grain can provide continuous protection from insect infestations and do not affect the baking quality of wheat.Inert dusts kill insects by causing moisture to move out of the insect's body. The dust either scratches through (diatomaceous earths) or absorbs (silica aerogel) the insect's waxy coating that normally prevents excessive loss of moisture to the dry grain and inter-granular air. The dust, because its mode of action is to dehydrate the insect, decreases in effectiveness as moisture contentof the grain increases(Shadia, 2011).

2.6.1 Potentials of diatomaceous earth in the control of insect pest

Diatomaceous Earth (DE) is a soft rock that is the fossilized remains of unicellular algae called diatoms. Depending upon the geological sources, it is made of pure amorphous silicon dioxide, which is non-toxic to mammals. These different geological sources have different efficiencies (Koranic, 1998). Diatomaceous earth removes the insect's cuticular waxes and insects die from desiccation (Ebeling, 1971); for seed treatment, it is usually mixed into the grain as a powder. It is inert, and as long as grains remain dry (below 15°C moisture, content), it will not lose its activity.

Diatomaceous Earth also known as diatomite, or kieselgur/kieselguhr, is a naturally occurring, soft, siliceous sedimentary rock that is easily crumbled into a fine white to off-white powder. Depending on the granularity, this powder can have an abrasive feel, similar to pumice powder, and is very light as a result of its high porosity. The typical chemical composition of oven-dried diatomaceous earth is 80 to 90% silica, with 2 to 4% alumina (attributed mostly to clay minerals) and 0.5 to 2% iron oxide (Antonides, 1997). One type of diatomaceous earth, commercially named "Insecto", is effective in controlling pests of stored grain. The high silica content must have a lethal effect on insects(Suyono and Naito, 1991).Plate V shows the picture of diatomaceous earth while Plate VI shows the picture of a processed diatomaceous earth.

Diatomaceous earth is an inorganic product that is used for protection of stored produce and is both non-toxic to mammals. Diatomaceous Earth is obtained from deposit of diatomite- fossilized sedimentary layer of tiny phytoplankton called diatoms.

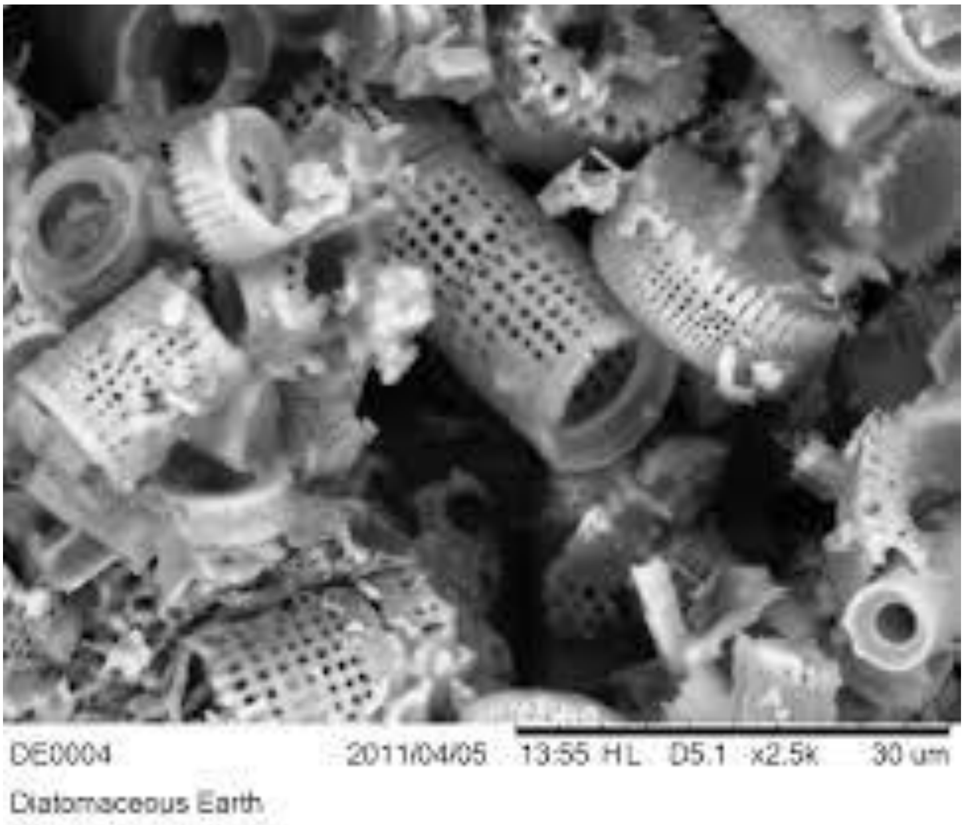

Plate V: Diatomaceous Earth

Plate VI:Processed Diatomaceous Earth

Diatomaceous earth also known as inert dust can be derived from diatomaceous algae fossils, which naturally possessed a thin silica layer. Dust particles adhere to the insect body causing dehydration(Le-patoured, 1986; Aldryhim, 1990; Lorini and Galley, 2003).

Diatomaceous Earth is used as a safe product and is of lasting insecticide effect, as it does not loose efficiency along time. Other inert dusts, such as the silica compound are reported to also have insecticidal properties. These are derived from mineralized rocks and can be used in the control of stored grain pests since they have silicate in their composition (Subramanyam and Roesli, 2000).

It has been documented that Diatomaceous Earth is very effective against stored product insects, and several Diatomaceous Earth formulations are now registered worldwide for use directly on commodities(Subramanyam and Roesli, 2000).However, several factors restrict their wide use. One of the most important is the target species, since Diatomaceous Earth's efficiency varies among different species(Subramanyam and Roesli, 2000; Fields and Koranic, 2000; Athanassiou and Kavallieratus, 2005), or even among different life stages of the same species(Mewis and Wrichs, 2001; Vayias and Athanassiou, 2004).

A second factor, which seems equally important, is the Diatomaceous Earth formulation itself. Although the insecticidal properties of all Diatomaceous Earth, are affected by the same parameters(Koranic, 1997; Koranic, 1998), the insecticidal values against a given species varies among commercially available Diatomaceous Earth formulation(Subramanyam and Roesli, 2000; Fields and Koranic, 2000; Athanassiou and Kavallieratus, 2005). These drawbacks are very serious, since the uses of each Diatomaceous Earth formulation must be assessed separately against each stored product insect pest(Shadia, 2011).

2.6.2 Ash of Rice husk

Rice husks are the natural sheaths that form on rice grains during their growth. Removed during the milling of rice, these have no commercial interest however, can be made useful through a variety of thermochemical conversion process. The major compounds from rice husks are silica and cellulose which yields carbon when thermally decomposed. On the majority of rice producing countries much of the husks produced from the processing of rice is either burnt or dumped as wastes. The ash is 92 – 95% silica, highly porous and light weight, with a very external surface area(Adylov, et al., 2003).Rice husk contains 75-90 % organic matter such as cellulose, lignin etc. and rest of mineral components such as silica, alkalis and trace elements. Rice husk is unusually high in ash compared to other biomass fuels in the range of 10-20%. The ash is 87-97% silica, highly porous and light- weight, with a very high external surface area. Presence of high amount of silica makes it a valuable material for use in industrial application. Other constituents of Rice Husk Ash (RHA), such as K_2O, Al_2O_3, CaO, MgO, Na_2O, $Fe_2O_3$are available in less than 1 %. The main ingredient of rice husk ash is silica (SiO_2), accounting for 96% of the total content(Suyono and Naito, 1991; Naito, 1997; Kumar *et al*., 2013).Plate VII shows the picture of processed rice husk.

PlateVII:Rice Husk

2.6.2.1 Potentials of rice husk ash (RHA) in the control of insect pest

Rice husk ash (RHA) is a term describing all types of ash produced from burning rice husks which vary considerably according to burning techniques. The silica in the ash undergoes structural transformations depending on conditions (time, temperature, etc.) of combustion. At 550 to 800^{o}C amorphous ash is formed and at temperature greater than this, crystalline ash is formed(Joseph *et al*., 1989). The change from amorphous to crystalline ash occurs at approximately 800^{o}C, although the process is often ‘incomplete’ until 900^{0}C is achieved. All the combustion processes devised to burn rice husks remain below 1440^{0}C, which is the rice husk melting point. The rice husk ash obtained at 1000^{0}C will exhibit excellent chemical activities and will be white in colour. These types of silica have different properties and it is important to produce ash of the correct specification for the particular end use. Rice husk ash has so many applications due to its various properties e.g. for control of insect pests in stored food stuffs.Rice husk ash also includes a large amount of needle-like particles (Plate VIII) that are probably derived from the setae covering the outer surface of the rice hull.

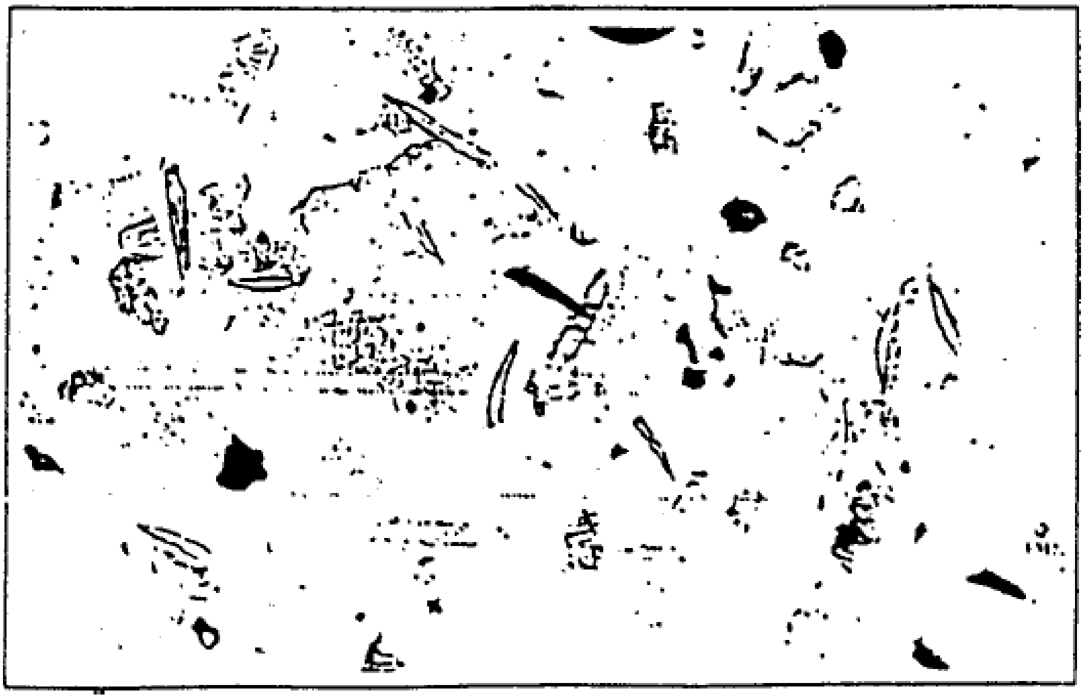

Plate VIII. Microscopic appearances of rice husk ash
Source:(Suyono and Naito, 1991; Naito, 1997)

These needle-like particles may trigger a physical reaction on the skin of insects, and the resulting physical disturbance may help cause their death. It is also believed that inert substances generally cause a loss of body moisture(Suyono and Naito, 1991; Kumar *et al*., 2013; Naito, 1997).Plate IX shows the picture of processed rice husk ash.

PlateIX:Rice Husk Ash

2.6.2.2 Composition of rice husk

Rice husk contains 75-90 % organic matter such as cellulose, lignin etc. and rest mineral components such as silica, alkalis and trace elements. Rice husk is unusually high in ash compared to other biomass fuels in the range 10-20%. The ash is 87-97% silica, highly porous and light- weight, with a very high external surface area. Presence of high amount of silica makes it a valuable material for use in industrial application. Other constituents of Rice Husk Ash (RHA), such as K_2O, Al_2O_3, CaO, MgO, Na_2O, Fe_2O_3 are available in less than 1 %. Rice husk having bulk density of 96-160kg/m^3, oxygen 31-37%, nitrogen 0.23-0.32%, sulphur 0.04-0.08%(Kumar *et al*., 2013).

2.6.3 Periwinkle shell dust (PSD)

Periwinkles are invertebrates and classified to belong to the phylum *Mollusca* and class *Gastropoda*(Ehigiator and Oterai, 2012). They are widely distributed shore snails, chiefly herbivorous and they have a dark and sometimes spiral banded shell that readily withstands the buffeting waves characterized by turreted, granular and spiny shells with tapering ends (Jamabo and Chinda, 2010; Ehigiator and Oterai, 2012). Freshwater prawns of the genus *Macrobrachium*are decapod crustaceans belonging to the family *Palaeomonidae*. *Macrobrachiumspp*are found in most inland freshwater areas and occur throughout the West Africa region. Freshwater prawns, like all crustaceans, have a hard outer skeleton or shell that must be shed regularly in order for growth to occur (D'Abramo and Brunson, 1996; Ehigiator and Oterai, 2012).

The common periwinkle or winkle *(Littorinalittorea*) is a species of small edible sea snail, a marine gastropod mollusc that has gills and an operculum, and is classified within the family *littorinidae*,(Reid and Gofas, 2011). The shell is broadly ovate, thick and sharply pointed except when eroded(Benson, 2011). The shells contain six to seven whorls with some fine threads and wrinkles. The colour is variable from greyish to grey- brown, often with dark spiral bands (Benson, 2011). The base of the columella is white, the shell lacks an umbilicus. The white outer lip is sometimes checked with brown patches. The inside of the shell has a chocolate brown colour. The width of the shell ranges from 10 to 12mm at maturity, with an average length of 16-36 mm, or 52 mm(Welch, 2010; Benson, 2011). Plate X shows the picture of periwinkle shells.

PlateX:Periwinkle Shell

2.6.3.1 Potentials of periwinkle shell dust(PSD) in the control of insect pest

It has been reported in literature that the periwinkle shell ash had up to 44.26% lime (calcium oxide) as its oxide composition which make it a potential to control pest (Golob and Webley, 1980). The edible portion of *T. fuscatus*had the lowest calcium value (44.73mg/100g). The magnesium concentration varied between 2.48 – 21.70mg/100g. The phosphorus content was generally high in all the body parts species ranging from 100.81-106.71 mg/100g. The zinc content was very low compared to other metals with values ranging between 1.16 and 1.24 mg/100g(Ehigiator and Oterai, 2012).

2.6.4 Prawn shell ash (PSA)

Prawns are a group of popular sea foods found worldwide. They are physically similar and very closely related to shrimps, belonging to the same order Decapoda of the class Crustacea and only distinguishable in their gill structure. In markets and restaurants the two words (shrimps/ prawns) are used interchangeably. Prawns serve a number of economic purposes including source of food, foreign exchange, income and provision of employment (Akegbejo-Samson, 1997). Prawns are highly relished, and amongst the leading priced sea foods on the global menu. Prawn have been reported to be the most important internationally traded fishery commodity in terms of value (Gillett, 2008). In many tropical developing countries including Nigeria, prawn is the most valuable fishery export, while the employment aspect is also significant(Areola, 2007; Gillett, 2008). The global market for prawns is ever on the increase largely due to high rate of consumption in the US, Europe and Japan(Zabbey *et al*., 2010). In Nigeria, the demand for prawns far outstrips its supply(Sogbesan *et al*., 2005; Areola, 2007). In the diet, prawns supply good quality proteins, vitamins A and D, and several dietary minerals especially calcium and iron(Abulude *et al*., 2006). When consumed whole, they also supply appreciable quantities of dietary fibre, which is low or undetectable in the flesh(Adeyeye and Adubiaro, 2004). It was revealed that prawns are extremely low in fat and calories, making them a very healthy choice of food(Ravichandran *et al*., 2009). Apart from its low fat content, prawns serve as a major source of omega-3 fatty acids which lower the total serum cholesterol levels(Stansby, 1982), and also prevent heart diseases and a number of circulatory problems. On account of the very low animal protein intake by Nigerians due primarily to the decrease in per capita production, prawns have become a major source of animal protein especially for the low income earners because of its low price and availability(Adeyeye, 1996).

Prawns are among the cheapest sources of animal protein and account for about 40 % of the total animal protein intake of the average Nigerian(Oladimeji and Sadiku, 1991). Like other crustaceans such as crayfish, crabs and lobsters, prawns are rich in chitin a structural polysaccharide that has proven useful for several medical and industrial purposes(Park and Kim, 2010; Morganti *et al*., 2011). In Nigeria as well as many other parts of the world, prawn consumers seem to be more interested in the consumption of the fleshy parts of the shell fish, while the hard parts are often discarded. Thus, preparing prawns for consumption usually involves removing the hard parts such as the head, shell or exoskeleton, carapace and tail(Zhai and Hawkins, 2002; Gimeno *et al*., 2007). Plate XI shows the picture of prawn.

Plate XI:Picture of Prawn

2.6.4.1 Potentials of prawn shell ash (PSA) in the control of insect pest

A number of studies have shown that the crustacean shells are the most important source of chitin for commercial use due to its high content and readily available(Gagné and Simpson, 1993; Subasinghe, 1999; Wang and Xing, 2007; Morganti *et al*., 2011).

The exoskeleton and the appendages of *M. vollenhovenii*had the highest calcium (52.00mg/100g). The whole portion of *M. vollenhovenii*had highest content of phosphorus (102.67mg/100g) while the exoskeleton and appendages of *M. vollenhovenii*had the lowest (100.81mg/100g). (Ehigiator and Oterai, 2012).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Culture and Colony Establishment of the Red Flour Beetle, *Triboliumcastaneum*

Adults of*Triboliumcastaneum*were obtained from cultures maintainedin the storage entomology laboratory, which were verified in the insect museum of the Department of Crop Protection, Institute for Agricultural Research (IAR), Ahmadu Bello University, Samaru, Zaria. Clean grains were obtained and disinfested for three days with Aluminium phosphide in an airtight kilner jar. The cleaned grains were exposed to air dry for three days to remove any residue of the chemical/phostoxinbefore culturing of the beetle. The insects were sieved out from the culture and 40 insects weresub-cultured in two different 1000 ml Raven Head Kilner jars partially filled with wheat flour to mate and oviposit. The jars were left to stand for a period of 40 to 45 days until the adult emerged, under laboratory condition with temperatures ranging from 20-35°C and relative humidity of 30 to 95%. Freshly emerged adult beetles were sieved out and used for infestation. A mercury thermometer and a hydrometer were used to record the daily temperature and relative humidity in the laboratory throughout the period of the study.

3.2 Procurement and Treatment of Wheat Grains

Clean wheat grains were obtained from Samaru market, Zaria for the experiment. The grains were taken to the Storage Entomology Laboratory, Department of Crop Protection, Faculty of Agriculture, Ahmadu Bello University Zaria. Phostoxin tablet were obtained from agro-allied shop at Samaru, Zaria and were used to disinfect the grains in an airtight container for three days and air dried prior to the start of the experiment.

3.3 Sources of Silica-Based Dusts Materials

Raw Diatomaceous Earth formulation was obtained from the Department of Geology, Ahmadu Bello University,Zaria. The food grade (amorphous silica) diatomaceous earth was analysed in the Department of Geology Laboratory. Other materials (Periwinkle shell, Rice husk ash and prawn shell) were obtained on request from SabonGari Market, Zaria, Kaduna State. The rice husk ash was dissolved with water in perforated container and another container was kept under the perforated container to collect the distillate while additional water was continuously added to the perforated one. The distillate collected was subjected to heating by boiling to evaporate the water then a crystalized form of concentrate was formed which was grinded to powder as rice husk concentrate. Pirimiphos-methyl (Actellic E.C. 2 %) was used as standard check with an untreated check. The Actellic E.C wassourced from the Storage Entomology Laboratory of the Department of Crop Protection, Faculty of Agriculture, Ahmadu Bello University, Zaria.

3.4 Treatments and Experimental Design

One hundred gram sample of the wheat grains were weighed into ninety (90) clean jars. The various concentrations of silica-based dusts treatments were applied at different rates (0.25, 0.5, 1.0, 1.5 and 2.0 g/kg) including the standard and untreated check. All treatments were repeated three times and the jars were then infested with ten (10) pairs of freshly emerged sexed-adult of *Triboliumcataneum*(see Plate XI) and covered with a muslin cloth. Each jar was shaken vigorously by hand to achieve uniform distribution. The jars were capped with perforated lids.All the treatments including the untreated control and standard check were labelled accordingly and arranged in a completely randomized design on a laboratory bench at the Storage Entomology Laboratory of the Department of Crop Protection, IAR, Zaria.

Plate XI: Female (Left) and Male (Right) Adult *TriboliumCastaneum*

3.5 Data Collection

3.5.1 Mortality count

Adult Mortality was taken at 24, 48, and 72 hours post-treatment. After the 72 hours mortality count, both live and dead insects were removed and discarded.The observation involved pouring the content of each jar gently on a plastic tray and separating the insect from wheat grains and the dead insect were recorded in each treatment. Insects were considered dead when they did not respond to probe with a pin.

3.5.2 Progeny emergence

Emerged progenies were counted after 40 and 80 days of infestation to record F_1 and F_2progeny respectively and then the live and dead insects were removed. Data from all treatments were recorded and collated.

3.5.3 Percentage grain damage

Percentage damaged kernels were assessed at the end of the experimentby taking hundred grains sub-sample from each repetition and the grains were observed and sorted out into damaged and undamaged. The grains in each category were counted and used to calculate the percentage damaged for 40 and 80 days after infestation for each treatment using the expression in the Equation below.

$$\% \text{ Damaged} = \frac{\text{No. of damaged grains}}{\text{No. of grain sampled}} \times 100$$

3.6 Statistical Analysis

All data collected weresubjected to square roottransformation (x + 0.5).Data was analysed using SAS software package and Analysis of Variance (ANOVA) was carried out. Differences between treatment means were separated by Student Newman Keul Significant Difference (SNK) test at 0.05% level of probability.

CHAPTER FOUR

4.0 RESULTS

4.1 The Efficacies of Silica-Based Dusts on the Mortality of Adult *Triboliumcastaneum*at 24, 48 and 72 Hours after Infestation

Results on the efficaciesof some silica- based dust; Diatomaceous Earth (DE), Periwinkle shell dust (PSD),Rice husk ash concentrate (RHAC), Prawn shell ash (PSA) and Actellic (E.C.) on the mortality of adult *T.castaneum*at 24 hours post-treatmentis presented in Table 4.1.The data showed that, silica- based dusts andActellic (EC) caused higher mortality than the untreated check. At 24 hours after infestation, complete mortalitywas observed in standard check at rate of 1.50 and 2.00 g/100 gof treated wheat grain. DE, PSD, RHAC and PSat 0.25 and 0.50 levels were not significantly different (P>0.05)from the untreated check. However, higherrate of 1.00 – 2.00 g/100 g of treated wheat grainsled to higher mortality of *T. castaneum.* Which were similar to the standard check. At 48 hours after infestation, the result showed that there was complete mortality of the adult *T.castaneum* with DE at level of 2.00g/100 g of treated wheat grains. At 0.25g/100 g, all the silica-based dusts grains were significantly (P>0.05) lower than the standard check in causing mortality of *T. castaneum,* but significantly (P>0.05) better than the control. DE at a concentration of 0.5 g/100 g of treated wheat grains was as good as the standard check at 48 hours after treatment. There were no significant differences among PSD, RHAC and PS at 0.5, 1.00, 1.50 and 2.0 on adult mortality of *T. castaneum,* but had higher insect mortality than the control. At 72 hours after infestation,the result showed thatmortality in standard check rises to 100 % (3.17) at all the treatment rates. There was no significant difference between DE and the standard check at rates of 0.25 – 2.00 g/100 g of treated wheat grains. DE and PSD at rates of 1.00 – 2.00 g/100 g of treated wheat grains was not significantly different from the standard check in causing the mortality of *T. castaneum*. All the treatments were significantly better than the control at all concentrations in causing mortality of *T. castaneum*.

Table 4.1: Mean Mortality of Adult *Triboliumcastaneum*.

Treatments	Mortality Counts		
	24 hrs	48 hrs	72 hrs
Standard check	2.92[a]	3.21[a]	3.24[a]
Diatomaceous Earth	1.51[b]	2.96[b]	3.21[a]
Periwinkle Shell Dust	1.08[c]	1.49[c]	2.75[b]
Rice Husk Ash Concentrate	1.19[c]	1.41[cd]	1.75[c]
Prawn Shell	1.01[c]	1.23[d]	1.55[d]
Control	0.73[c]	0.93[e]	1.02[e]
SE±	0.059	0.065	0.062
Rate of Application g/100g wheat grains			
0.25	1.21[b]	1.70[b]	2.16[ab]
0.50	1.22[b]	1.76[b]	2.10[b]
1.00	1.49[a]	1.89[ab]	2.32[a]
1.50	1.52[a]	1.98[a]	2.31[a]
2.00	1.58[a]	2.01[a]	2.37[a]
SE±	0.053	0.058	0.058
Interaction			
S × R	NS	NS	*

Means followed by the same letter(s) in the same column are not significantly different at P>0.05 using SNK

* Significant

** Highly Significant

NS Non-Significant

4.2 Effect of Silica-Based Dust on the F_1 and F_2 Progeny Emergence of *TriboliumCastaneum*at 40 and80 Days after Infestation

Data on the relative effect of some silica- based dust; Diatomaceous earth (DE), Periwinkle shell dust (PSD),Rice husk ash concentrate (RHAC), Prawn shell (PS) and Actellic (EC) on the progeny emergence of*T.castameum*at 40 anddays after infestation is presented in Table 4.2. At 40 days, the result showed that there was total control of progeny emergence in the standard check. At 0.25g/100 g of treated wheat grains, all the treatments did not show any significant difference in supressing the F_1 progeny emergence.At 0.50g and 1.00 g/100 g of treated wheat grains, all the treatments were as good as the standard check in suppressing the F_1 progeny emergence. At higher concentrations of 1.50 g and 2.00g/100 g of treated wheat grains, the treatments did not show any difference with the control. However, at 80 days after infestation,the resultindicated that there was total suppression of progeny emergence in the standard check which was highly significant compared to the silica based dusts. DE at 0.50 g and 1.00 g/100 g of treated wheat grains was as good as the standard check in suppressing F_2 progeny emergence. All other treatments were not significantly different from the standard check at all concentrations above 0.25 g/100 g of treated wheat grains in suppressing the F_2 progeny emergence, except PS which was not as good as other treatments but was significantly better than the untreated control.

Table 4.2: Means of Progeny Emergenceof Adult *Triboliumcastaneum*.

Treatments	Progeny Emergence	
	40 days	80 days
Standard check	0.71[b]	0.71[c]
Diatomaceous Earth	0.96[b]	0.77[c]
Periwinkle Shell Dust	1.02[b]	1.04[c]
Rice Husk Ash Concentrate	1.86[b]	0.73[c]
Prawn Shell	0.86[b]	1.74[a]
Control	1.85[b]	1.37[b]
SE±	0.114	0.098
Rate of Application g/100g wheat grains		
0.25	1.06[a]	0.99[a]
0.50	1.07[a]	1.19[a]
1.00	1.01[a]	1.20[a]
1.50	1.18[a]	0.93[a]
2.00	0.99[a]	1.18[a]
SE±	0.104	0.088
Interaction		
S × R	NS	NS

Means followed by the same letter(s) in the same column are not significantly different at P>0.05 using SNK

* Significant

** Highly Significant

NS Non-Significant

4.3 The Effect of Silica-Based Dusts on Percentage Grains Damaged by*Triboliumcastaneum* at 80 Days after Infestation

The effect of silica-based dusts on percentage grains damaged by *TriboliumCastaneum* at 80 Days after Infestation for first and second trials was presented in Table 4.6. The result showedthat all the silica based dusts were not better than the control in protecting the wheat grains against damage by *T.castaneum*, at level of 0.25 and 0.50 g/100 g of treated wheat grains. At 1.00-2.00 g/100 g of treated wheat, DE, PSD RHAC and PS were as good as the standard check in protecting the wheat grains against damage by *T.castaneum*. Plate XII shows the picture of the damaged wheat by T.*castaneum*.

Table 4.3: Means of Percentage Damaged Grainsof Adult *Triboliumcastaneum*.

Treatments	Percentage Damaged Grains
Standard check	0.71[d]
Diatomaceous Earth	1.24[c]
Periwinkle Shell Dust	2.26[b]
Rice Husk Ash Concentrate	1.32[c]
Prawn Shell	2.79[a]
Control	2.19[b]
SE±	0.115
Rate of Application g/100g wheat grains	
0.25	2.21[a]
0.50	1.83[b]
1.00	1.96a[b]
1.50	1.36[c]
2.00	1.42[c]
SE±	1.105
Interaction	
S × R	**

Means followed by the same letter(s) in the same column are not significantly different at P>0.05 using SNK

* Significant
** Highly Significant
NS Non-Significant

Plate XII: Damaged Wheat by *T.castaneum*

4.4 The Interaction Effect of Silica-Based Dusts and Rates on Mortality at 72 hours after Infestation

The interaction effect of silica-based dusts and rate of application (g/100 g of wheat grain) is given in Table 4.4. For all concentrations, standard check had the highest mortality rate at 72 hours after infestation, but not significantly different from diatomaceous earth. While recorded significantly higher mortality rate than other treatments at rates 0.25, 0.5 and 1.0 g/100 g, there was however no significant difference between standard check and periwinkle shell dust at rates 1.5 and 2.0 g/100 g. Control treatment recorded the least mortality across all dust concentrations. Furthermore, at 0.25 and 0.5g/100g wheat grain, the result showed that there was no significant difference between standard check with Diatomaceous earth and prawn shell with untreated check but periwinkle shell dust and rice husk ash concentrate were significantly different from each other and all the other treatment. There was no significant difference between the rates of 1.0, 1.5 and 2.0g/100g wheat grain.

Table 4.4: Interaction Effect of Silica-based Dusts and Rates on Mortality at 72 hours after Infestation

TREATMENT	RATES				
	0.25	0.5	1.0	1.5	2.0
Standard check	3.24^{a}	3.24^{a}	3.24^{a}	3.24^{a}	3.24^{a}
Diatomaceous Earth	3.13^{ab}	3.19^{ab}	3.24^{a}	3.24^{a}	3.24^{a}
Periwinkle Shell Dust	2.445^{cd}	2.19^{de}	2.80^{bc}	3.13^{ab}	3.19^{ab}
Rice Husk Ash Concentrate	1.67^{fg}	1.63^{fgh}	1.91^{ef}	1.78^{f}	1.76^{f}
Prawn Shell	1.27^{hijk}	1.32^{ghij}	1.74^{f}	1.53^{fghi}	1.88^{ef}
Control	1.22^{ijk}	1.04^{jk}	1.00^{jk}	0.94^{jk}	0.90^{k}
SE±	0.143				

4.5 The Interaction Effect of Silica-Based Dusts and Rates on Grain Damage

The interaction effect of silica-based dust and rate of application (g/100 g of wheat grain) is given in Table 4.5. For all concentration, standard check had the lowest grain damage after 80 days of infestation, but not significantly different from diatomaceous earth from the rates 0.5-2.00 g/100g wheat grains. Periwinkle shell dust at rates of 1.5 and 2.00g/100g wheat grains was not significantly different from standard check and diatomaceous earth. While at the rates of 0.5g - 2.00g/100g wheat grains rice husk ash concentrate was not significantly different from standard check, diatomaceous earth and periwinkle shell dust. Furthermore, at 0.25, the result recorded that there is significant difference at 0.25 g /100 g the result recorded that there significant difference between standard check and other treatments, at 0.5 g /100 g to 2 g /100 g wheat grains, standard check, DE, and RHC recorded no significant difference. However, PSD was not significantly difference from standard check from the rate of 1.5 – 2.0 g/ 100 g wheat grains while PRN and control are not significantly different from each other at all the rate in which they showed the highest grain damaged.

Table 4.5: Interaction Effect of Silica-based Dusts and Rates on Grain Damage

TREATMENT	RATES				
	0.25	0.5	1.0	1.5	2.0
Standard check	0.71^{i}	0.71^{i}	0.71^{i}	0.71^{i}	0.71^{i}
Diatomaceous Earth	1.86^{defgh}	1.35^{ghi}	1.22^{ghi}	0.98^{hi}	0.80^{i}
Periwinkle Shell Dust	3.32^{ab}	2.49^{bcd}	2.50^{bcd}	1.51^{efghi}	1.47^{efghi}
Rice Husk Ash Concentrate	2.41^{bcde}	1.39^{fghi}	1.32^{ghi}	0.80^{i}	0.71^{i}
Prawn Shell	2.58^{bcd}	3.07^{bc}	3.61^{b}	2.04^{defg}	2.68^{bcd}
Control	2.35^{cdef}	1.99^{defg}	2.37^{bcde}	2.11^{cdefg}	2.16^{cdefg}
SE±	0.258				

CHAPTER FIVE

5.0 DISCUSSION

5.1 Effect of Silica- Based Dusts on Adult Mortality of *Triboliumcastaneum*at 24, 48, 72 hours after Infestation

The study revealed that, the silica-based dust: Diatomaceous earth (DE), Periwinkle shell dust (PSD), Rice huskash concentrate (RHAC), Prawn shell dust (PS) andActellic (EC) and control applied at 0.25, 0.50, 1.00, 1.50 and 2.00g/100g of wheat grains significantly ($p<0.05$) showed higher adult mortality of *Triboliumcastaneum*compared to the untreated check. At 24 hours, all the treatments at lower rates of 0.25 and0.5 were not different from the control but at higher rates of 1.00-2.00g/100g, DE was better than all other treatments in causing adult mortality but not as good as the standard check. The other treatments were significantly better than the control At 48 hours the results revealed that, DE at concentrations above 0.25 g/100g was as good as the standard check in causing *T.castaneum* mortality. All other treatment were not as good as the standard check but were significantly better than the untreated control, at concentration above 0.25 g/100g. Furthermore, 72 hours mortality record showed that DE even at the lowest concentration was as good as the standard check, while all the other treatments were significantly better than the untreated check. All the silica based dusts and Actellic (EC), showed higher mortality than control check mean-while, rate means also showed that as the rate of silica-based dust was increased from 0.25 to 2.00g/100 g, the insect mortality also increased (the higher the concentration, the higher the insect mortality and the more the exposure time, the more the mortality). This stands in accordance with the report by Shayesteh and Ziaee in 2007 where they observed that; longer exposure interval is needed to achieve 100 % mortality for adult *T. castaneum* because the longer the insects walk over the treated substrates, the more dusts particle were trapped by their bodies, resulting in water loss and death through desiccation(Shayesteh and Ziaee, 2007).This also was reported by other previous researchers(Aldryhim, 1990; Aldryhim, 1993; Arthur, 2000; Vayias and Athanassiou, 2004; Athanassiou and Kavallieratus, 2005).

Diatomaceous earth is effective in controlling pests of stored grain. The high silica content, accounting for 97% of the total content,could have a lethal effect on insects(Suyono and Naito, 1991) also, the main ingredient of rice husk ash is silica (SiO_2), accounting for 96% of the total content. Rice husk ash also contain a large amount of tiny-sharp particles that are probably derived from the setae covering the outer surface of the rice hull. These needle-like particles may trigger a physical reaction on the skin of insects, and the resulting physical disturbance may help cause their death. It is also believed that inert substances generally cause a loss of body moisture(Suyono and Naito, 1991; Naito, 1997; Kumar *et al.*, 2013).

5.2 Effect of Silica-Based Dust on Progeny Emergence of *Triboliumcastaneum*

Silica based-dust and Actellic (EC) were found to be effective for the protection of wheat grains against progeny emergence of *Triboliumcastaneum.* There was 100 % progeny suppression at all concentration levels in treated check, DE and RHAC also had 100 % in level (0.50, 1.00 and ≥1.5 g/100 g), PSD had 99.67 % in level 1.5 g/100 g while PS had 98.67 in level of 0.25g/100g.The F_1progeny emergence was significantly reduced beyond 1.00 g/100g all the treatments including the standard check were not effective. The result showed that all treatments were as good as the standard check in suppressing F_2 progeny emergence and significantly better than the control.The concentration means revealed that progeny emergence reduced as the concentration increased. This agrees with(Lale, 2002) who reported that powders interfere with normal egg development by lengthening larval and pupa period which may subsequently reduce or deter progeny emergence.

5.3 Efficacy of Silica-Based Dusts on the Percentage Damaged Wheat Grains by *Triboliumcastaneum*

All the treatments at all concentration showed significant ($p<0.01$) reduction in grains damage by *T.castaneum*.Percentage damage at higher rate of 1.50 and 2.00 g/100 g showed lower damage than those of lower rate (0.25, 0.5 and1.00 g/100 g). Thus, increasing the concentration of all treatments which significantly reduced grain damage by *T. castaneum*. This showed that all treatments at concentrations of1.00 g/100g be used for effective or safe storage of wheat grains against *T.castaneum*.Diatomaceous earth is effective in controlling pests of stored grain. The high silica content must have a lethal effect on insects (Suyono and Naito, 1991). Also, rice husk ash also includes a large amount of needle-like particles that are probably derived from the setae covering the outer surface of the rice hull. These needle-like particles may trigger a physical reaction on the skin of insects, and the resulting physical disturbance may help cause their death. It is also believed that inert substances generally cause a loss of body moisture resulting to death by dehydration (Suyono and Naito, 1991; Naito, 1997; Kumar *et al*., 2013). Also, Naito (1999) introduced a low cost technology for controlling insect pests in Soya beans by using RHA. The insects are irritated by the high levels of silicon and the needle like particles (Naito, 1999).

CHAPTER SIX

6.0 SUMMARY, CONCLUSION AND RECOMMENDATION

6.1 Summary

This study was conducted to evaluate the efficacy of silica-based dusts (Diatomaceous earth, Periwinkle shell ash, Rice husk ash concentrate, Prawn shell and Actellic EC) which was used as treatment check to control *Triboliumcastaneun* on wheat grains.The result, had shown that DE and PSD were able to cause adult mortality as the synthetic insecticides. However, RHAC was the best among the dust to have protected the grains against progeny emergence as well as the DE and PSD at F_1 and F_2 generations. PS has shown to be unreliable to be used as protectant against *T. castaneum*. The effectiveness of these silica-based dusts is as a result of abrasive nature of the silica based dust on exoskeleton of the insect which caused dehydration and reduces the activities of *T. castaneum.* Furthermore, the treatments also reducedgrain damage.

6.2 Conclusion

This research has shown that DE, PSD and RHAC can be used to protect wheat grains against *T. castaneum* similar to the synthetic insecticides (Actellic EC) and had better performance compared to PS, in spiteof the fact that *T. castanuem* is known to be a secondary pest of stored product, its management should not be ignored in the stores. This research has shown that T. *castenuem* is assuming primary pest status because it caused severe damage on whole wheat grains. Considering these results, it can be inferred that silica based dusts were efficient in the control of the stored grains pests. These silica based dusts can be used in stored wheat as grain protectant to avoid the damage caused by the pests to maintain grain quality during storage.

6.3 Recommendation

It is recommended that extension workers should educate farmers on the benefit of this research and it should be adopted to save our health from the hazardous effect of synthetic chemicals.

REFERENCES

Abbas, M. (1988). First Joint one week intensive third training Course in international Wheat Production. 1-3. Mexico: CIMMYT/NAFPP/AERLS/NSS.

Abd-El-Aziz, S. E., and Sherief, M. A. (2010). Insecticidal Effects of Modified Diatomaceous Earth (DE) with different Hydroxides (MOH, M=Na,Ca,Al) against *Callosobruchus Maculatus* (F.) Beetles (Coleoptera: Bruchidae) on Stored Cowpea Grains. *Journal of Entomological Research, 34*, 1-9.

Abulude, F. O., Lawal, L. O., Ehikhamen, G., Adesanya, W. O., and Ashafa, S. L. (2006). Distribution of Macrominerals in Four Prawns from the Coastal Area of Ondo State, Nigeria. *Journal of Fisheries International, 2*(4), 70-72.

Adebayo, R. A., and Ibikunle, O. (2014). Potentials of Rice Husk Ash, Cowdung Ash and Powdered Clay as Grain Protectants against *Callosobruchus maculatus* (F) and *Sitophilus zeamais* (Mots). *Journal of Applied Tropical Agriculture, 19*(2), 48-53.

Adedire, C. O., and Lajide, L. (2001). Efficacy of Powders of Some Tropical Plants in the Control of Pulse Beetle. *Applied Tropical Agriculture, 6*, 11-15.

Adeyeye, E. L. (1996). Waste Yield, Proximate and Mineral Composition of Three Different Types of Land Snails found in Nigeria. *International Journal of Food Sciences and Nutrition, 47*(2), 111-116. Retrieved from http://dx.doi.org/10.3109/09637489609012572

Adeyeye, E., and Adubiaro, H. (2004). Chemical Composition of Shell and Flesh of Three Prawn Samples from Lagos Lagoon. *A Journal of the Science of food and Agriculture, 84*(5), 411-414. Retrieved from http://dx.doi.org/10.1002/jsfa.1649

Adylov, G., Faiziev, S. H., Paizullakuhanon, M., Mukhsimov, S., and Nodirmatov, E. (2003). Silicon Carbidematerials obtained from Rice Husk. *Technical Physics. Lett., 29*(3), 221-223.

Akegbejo-Samson, Y. (1997). Introduction to Aquaculture Fisheries Management in Nigeria. *Natural Resources Series 2* (pp. 9-15). Abeokuta, Nigeria: Goal Educational Publishers.

Alanko, K., Tuomi, T., Vanhanen, M., Pajari-Backas, M., Kanerva, L., Havu, K., Bruynzeel, D. P. (2000). Occupational IgE-Mediated Allergy to *Tribolium Confusum* (Confused Flour Beetle) Allergy. *55*, 879-882.

Aldryhim, Y. N. (1990). Efficacy of Diatomaceous Silica Dust, Dryasids, Against *Tribolium confusum* Duval *Sitophilius granalius* (L) (Coleoptera: Tenebrionidae and (Curcuvionidae). *Journal of Stored Products Research, 26*, 207-210.

Aldryhim, Y. N. (1993). Combination of Classes of Wheat and Environmental Factors Affecting the Efficacy of Amorphous Silica Dust, Dryacids, Against *Rhyzopertha dominica* (F.). *Journal of Stored Products Research, 29,* 271-275.

Amatobi, C. I. (2007). Arthropod Pests of Crops in Nigeria: General Biology, Natural Enemies and Control. 191.

Aminu-Kano, M., and Ikwelle, M. C. (1998). Wheat Research in Nigeria. *In J. A. Valencia, E. A Salako, M. C Ikwelle, M. Aminu-Kano, I. U. Abubakar, S. Miko and J. Jaryum. Wheat production in Nigeria Prospect and Constraints* (pp. 25-35). Proceedings of the National Wheat Production Workshop.

Anonymous. (1990). *Stored-Grain Insects.* New York: U.S.D.A. Agricultural Handbook, Oxford University Press.

Anonymous. (1991). *Report of the Stored Grain Research Laboratory.* Canberra: CSIRO.

Antonides, L. E. (1997). *Diatomite: USGS.* Retrieved December 12, 2010, from USGS Website: http://minerals.usgs.gov/minerals/pubs/commoditv/diatomite/250497.pdf

Appert, I. (1987). *The Storage of Stored Food Grains and Seeds.* London: Macmillian Publishers Ltd.

Arbogast, R. T., Kendra, P. E., Mankin, R. W., and McGovern, J. E. (2000). Monitoring Insect Pests in Retail Stores by Trapping and Spatial Analysis. *Journal of Economic Entomology, 93,* 1531-1542.

Areola, F. O. (2007). Fish Marketing and Export Potentials of Fish and Fisheries Products in Nigeria. *Paper presented at the Educative and Informative Aqua-cultural Workshop and Exhibitions tagged: Sustainable Fisheries Livelihood: Management and Food Security in Nigeria, (February 23, 2007).* Lagos.

Arthur, F. H. (2000). Impact of Food Source on Survival of Red Flour Beetle and Confused Flour Beetle (Coleopteran: Tenebrionidae) Exposed to DE. *Journal of Economic Entomology, 93*, 1347-1356.

Arthur, F. H., and Puterka, G. J. (2002). Evaluation of Kaolinite-based Particle Films to Control *Tribolium Species* (Coleoptera: Tenebrionidae). *Journal of Stored Product Research, 38*, 341-348.

Asawalam, E. F., Emesairue, S. O., and Hussanali, A. (2006). Constituents of the Essential Oil of Vernonia Amygdalina as Weevil Protectants. *Tropical and Subtropical Agroecosystems, 6*(2), 95-102.

Asawalam, E. F., Emosairue, S. O., Ekeleme, F., and Wokocha, R. C. (2007). Insecticidal Effects of Powdered Parts of Eight Nigerian Plant Species against

Maize Weevil *Sitophilus Zeamais* Motschulsky (Coleoptera:Curculionidae). *Electronic Journal of Environmental, Agriculture and Food Chemistry, 6*(11), 2526-2533.

Athanassiou, C. G., and Kavallieratus, N. G. (2005). Insecticidal Value of Diatomaceous Earth as a Grain Protestant. *Journal of Entomology, 55*(6), 964-970.

Athanassiou, C. G., Varias, B. J., Dimizasa, C. B., and Chelosa, N. G. (2003). Insecticidal Efficacy of Diatomaceous Earth against *Sitophilus Oryzae* (L) (Coleoptera. Tenebrionidae) on Stored Wheat. Influence of DoseRate, Temperature and Exposure Interval. *Journal of Stored Product Research, 41,* 47-55.

Banks, H. J., and Fields, J. B. (1995). Physical Methods for Insect Control in Stored-grain Ecosystem. (pp. 353-409). New York: In: Stored Gain Ecosystem, Jayas, D.S., N.D.G. White and W.E. Muir (Eds.). Marcel Dekker.

Bekele, A. J., Obeng-Ofori, D., and Hassanali, A. (1997). Evaluation of Ocimum Kenyense (Ayobangira) as a Repellence, Toxicants and Protectants in Storage against three Major Stored Product Insect Pests. *Journal of Applied Entomology*, 121-169.

Belderok, R. B., Mesdag, H., and Donner, D. A. (2000). *Bread-Making Quality of Wheat.* Springer.

Benson, A. J. (2011). *Littorina Littorea. USGS Nonindigenous Aquatic Species Database, Gainesville, FL.* Retrieved April 21, 2009, from USGS Website: http://nas.er.usgs.gov.queries/factsheet

Boeke, S. J., van Loon, J. J., van Huis, A., Kossou, D. K., and Dicke, M. (2001). *The Use of Plant Material to Protect Stored Leguminous Seeds against Seed Beetles: A Review.* Netherlands: Backhuys Publishers.

Bousquet, Y. (1990). *Beetles associated with Stored Products in Canada.* Ottawa: Canadian Government Publishing Centre.

Cauvain, S. P., and Cauvain, P. C. (2003). *Bread Making.* CRC Press.

D'Abramo, L. R., and Brunson, M. W. (1996). Biology and Life History of Freshwater Prawns. *Southern Regional Aquaculture Centre*, 483.

Dales, M. J. (1996). A Review of Plant Materials used for Controlling Insect Pests of Stored Products. *Natural Resource Institute (NRI) Bulletin 65, 65,* 1-84.

Delima, C. P. (1987). Insect Pests and Post Harvest Problem in Tropics. *Insect Science and Its Application*, 676-677.

Ebeling, W. (1971). Sorptive Dust for Pest Control. *Ann. Reviwed Entomology, 16*, 23-158.

Ehigiator, F. A., and Oterai, E. A. (2012). Chemical Composition and Amino Acid Profile of a Caridean Prawn (*Macrobrachium vollenhovenii*) from Ovia River and Tropical Periwinkle (*Tympanotonus fuscatus*) from Benin River, Edo State, Nigeria. *IJRRAS, 11*(1), 1-18. Retrieved from www.arpapress.com/Volumes/Vol11Issue1/IJRRAS_11_1_18.pdf

FAOSTAT. (2015). *Statistics of Wheat Production Quantity in Nigeria.* United Nation: Food and Agricultural Organization of the United Nation, Statistics Division.

Fields, P. G. (1992). The Control of Stored Product Insects and Mite with Extreme Temperature. *Journal of Stored Products Research, 28*, 89-118.

Fields, P. G., and Koranic, Z. (2000). The Effect of Grain Moisture Content and Temperature on the Efficacy of Diatomaceous Earth from Different Geographical Locations against Stored Products Beetles. *Journal of Stored Products Research, 36*, 51-53.

Fields, P. G., and Muir, W. E. (1996). Physical Control. In B. a. Subramanyam, *Integrated Management of Insects in Stored Products* (pp. 195-221). New York: Marcel Dekker Inc.

Gagné, N., and Simpson, B. K. (1993). Use of Proteolytic Enzymes to Facilitate the Recovery of Chitin from Shrimp Wastes. *Food Biotechnology, 7*, 253-263.

Gillett, R. (2008). *Global Study of Shrimp Fisheries. FAO Fisheries Technical Paper 475.* Rome: FAO.

Gimeno, M., Ramirez-Hernandez, J. Y., Mártinez-Ibarra, C., Pacheco, N., Garcia-Arrazola, R., Barzana, E., and Shirai, K. (2007). One-Solvent Extraction of Astaxanthin from Lactic Acid Fermented Shrimp Wastes. *Journal of Agricultural and Food Chemistry, 55*, 10345-10350.

Golob, P. (1997). Current status and future perspectives for inert dusts for control of stored product insects. *Journal of Economic Entomology, 33*, 69-79.

Golob, P. J., Mwanbula, V., Mhango, and Ngulube, F. (1982). The Use of Locally Available Materials as Protectants to Maize Grain against Insect Infestation during Storage in Malawi. *Journal of Stored Products Research, 37*, 67-74.

Golob, P., and Webley, D. J. (1980). *The Use of Plants and Minerals as Protectants of Stored Product Tropical Product Institute G138.* Cathan, UK.: Post-Harvest Pest and Quality Section Natural Resource Institute.

Golob, P., Moss, C., Males, M., Fidgen, A., and Evans, J. (1991). *The Spices and Medicinals as Bioactive Protectants for Grains.* Rome: FAO.

Hill, D. S., and Walker, J. M. (1990). *Pests and Diseases of Tropical Crops Vol. 2: Field Book.* United Kingdom: Longman Scientific and Technical.

Hill, I. D., Horvath, K., and Fasano, A. (1995). Epidemiology of Celiac Disease. *Am Journal of Gastroenterol, 90*(1), 163-164.

IITA. (2011). *Annual Reports on Maize Production.* Ibadan Oyo State: International Institute of Tropical Agriculture.

Jamabo, N., and Chinda, A. (2010). Aspects of the Ecology of Tympanotonus Fuscatus in the Mangrove Swamps of the Upper Bonny River, Niger Delta, Nigeria. *Journal of Biological Sciences, 2*(1), 42-47.

Joseph, S., Baweja, D., Crookham, G. D., and Cook, D. J. (1989). Production and Utilization of Rice Husk Ash Preliminary Investigations. *Third CANMET/ACI International Conference on Fly Ash, Silica Fume, Slag and Natural Pozzolans* (pp. 861-878). CANMET/ACI.

Koehler, P. G. (2003, April). *Pantry and Stored Food Pests.* Retrieved from EDIS: http://edis.ifas.ufl.edu/IG095 (27 May 2003)

Koranic, Z. (1997). Rapid Assessment of the Insecticidal Value of Diatomaceous Earth Without Conducting Biassay. *Journal of Stored Products Research, 33*, 219-229.

Koranic, Z. (1998). Diatomaceous Earth, a Group of Natural Insecticides. *Journal of Stored Products Research, 34*, 87-97.

Kumar, S., Sangwan, P., Dhankhar, R. M., and Bidra, S. (2013, December). Utilization of Rice Husk and Their Ash: A Review. *Research Journal of Chemical and Environmental Sciences, 1*(5), 126-129. Retrieved June 10, 2016, from http://www.aelsindia.com

Lale, N. E. (1994). Laboratory Assessment of the Effectiveness and Persistence of Powders of Four Spices on Cowpea Bruchid and Maize weevil in Airtight Facilities. *Journal of Agricultural Research, 11*, 79-84.

Lale, N. E. (1995). An Overview of the Use of Plant Products in the Management of Stored Product Coleopteran in the Tropics. *Postharvest News and Informations, 6*, 69-75.

Lale, N. E. (2001). The Impact of Storage Insect Pests on Post-harvest Loss and their Management in the Nigeria Agricultural System. *Nigerian Journal of Experimental and Applied Biology, 2*, 231-239.

Lale, N. E. (2002). *Stored Product Entomology and Acarology in Tropical Africa.* Maiduguri, Nigeria: Mole Publication.

Lale, N. E., and Ofuya, T. I. (2001). Evaluation of a New Insecticidal Formulation (F2) as a Protectant of Stored Wheat, Maize and Rice. *Journal of Stored Products Research, 40*, 317-330.

Lashiavo, S. R. (1988). Availability of Food as a Factor in Effectiveness of a Silica Aeraged against the Merchant Grain Beetle (Coleoptera: Cucujidae). *Journal of Entomolology, 81*, 1237-1240.

Le-patoured, G. N. (1986). The Effect of Grain Moisture Content on Toxicity of Sorptive Silica Dust on Four Species of Grain Beetle. *Journal of Stored Products Research, 22,* 63-69.

Lorini, I., and Galley, D. J. (2003). Estimation of Realized Heritability of Resistance to Deltrimetrin Insecticides in Selected Strains of *Rhyzopertha Dominica* (F) (Coleoptera- Bostrychidae). *Journal of Stored Products Research, 36*, 119-124.

Mahdi, S. H., and Khalequzzaman, M. (2006). Toxicity studies of some inert dusts with the cowpea beetle, *Callosobruchus maculates* (Fabricius) (Coleoptera: Bruchidae). *J. Boil. Sci.,, 6*, 402-407.

Mewis, I., and Wrichs, C. H. (2001). Action of Amorphous Diatomaceous Earth, Against Different Stages of the Stored Product Pests, *Tribolium Confusum* (Coleopteran; Tenebrionidae), Tenebrio Motitor (Coleoptera; Curcuclionidae) and *Plodia Interupunctella* (Lepidoptera; Pyralidae). *Journal of Stored Products Research, 37*, 153-164.

Morganti, P., Morganti, G., and Morganti, A. (2011). Transforming Nanostructured Chitin from Crustacean Waste into Beneficial Health Products: A Must for our Society. *Nanotechnology, Science and Applications, 4*, 123-129.

Mustapha, S. (1998). Wheat Production in Nigeria: Past, Present and Future Prospect. *In: J. A. Valencia, E. A.*

Naito, A. (1997). Some Technical Problems of Soybean Production in Indonesia. *Journal of Tropical Agriculture, 41*(3), 203-210.

Naito, N. (1999). *Low–cost Technology for Controlling Soybean Insect Pests in Indonesia*. Japan: Association for International Cooperation of Agriculture and Forestry.

Niber, B. T. (1994). The Ability of Powders and Slurries from Ten Plant Species to Protect Stored Grain from Attack by *Peostephanus Truncates*. Horn; (Coleoptera: Curculionidae). *Journal of Stored Product Research, 30*, 297-301.

Ofuya, T. I. (2003). *Beans, Insects and Man. Inaugural Lecture Series 35.* Akure, Nigeria: The Federal University of Technology.

Ogunwolu, O., and Odunlami, A. T. (1996). Suppression of Seed Bruchids *Callosobruchus Maculatus* (F.) Development and Damage on Cowpea Vigna unguiculata (L) Walp with Zanthoxylum Zanthoxyloides (Lam.) Waterm. (Rutaceae) Root Bark Powder when Compared with Neem Seed Powder and Pirimiphos-methyl. *Crop Protection, 15*, 603-607.

Oladimeji, A. A., and Sadiku, S. O. (1991). Mineral Constituents of Lates *Niloticus,Synodontis schall* and *Sarotherodon galilaeus* (Trewaves) from Zaria (Nigeria) Dam. *Journal of Animal Production Research, 11*, 45-52.

Olugbemi, L. B. (1990). Major Constraints and Remedies to Wheat Production in Nigeria. In A. J. Rayer, B. K. Kaigama, J. O. Olukosi, and A. B. Anaso, *Wheat Production in Nigeria: Production, Processing, and Utilization* (pp. 3-9). Nigeria: Rayer, A J; Kaigama, B K; Olukosi, J O; Anaso, A B eds.

Palmer, J. J. (2001). *How to Brew.* Defenestrative Pub Co.

Park, B. K., and Kim, M. (2010). Applications of Chitin and its Derivatives in Biological Medicine. *International Journal of Molecular Sciences, 11*(12), 5152-5164.

Paulraj, M. G., and Shayaraj, K. (2002). Efficacy of *Ecliptaalba L*. Hassk and *Ocimum sanctum* Linn. Leaves extracts and powders against *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae) in Groundnut. (p. 80). Chennai: Vistas of Entomological Research for the New Millenium Gill Research Institute.

Perez-mendoza, J. (1999). Survey of Insectisidal Resistance in Mexican Population of Maize Weevil, *Sitophilus zeamais* Motschulky (Coleopteran: Curculionidae). *Journal of Stored Product Research, 36*(1), 107-115.

Quarles, W. (1992). Silica gel for pest control. *IPM Practitioner, 14*, 1-11.

Ravichandran, S., Ramesh Kumar, G., & Prince, A. R. (2009). Biochemical Composition of Shell and Flesh of the Indian White Shrimp *Penaeus indicus* (H. milne Edwards 1837). *American-Eurasian Journal of Scientific Research, 4*(3), 191-194.

Reid, D. G., and Gofas, S. (2011). *Littorina littorea (Linnaeus, (1758).* Retrieved May 16, 2011, from World Register of marine Species: http://www.marinespecies.org./aphia. 2011-05-16.

Shadia, E. A.-A. (2011). Control Strategies of Stored Product Pests. *Journal of Entomology, 8*, 101-122. doi:10.3923/je.2011.101.122

Shawir, M., Le-patourel, G. N., and Moustafa, F. I. (1988). Amorphous Silica as an Additive to Dust Formulation of Insecticides for Stored Grain Pest Control. *Journal of Stored Product Research, 34*, 23-36.

Shayesteh, N., and Ziaee, M. (2007). Insecticidal Efficacy of Diatomaceous Earth against *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae. *Caspian Journal of Environmental Science, 5*(2), 119-123.

Slafer, G. A., and Satorre, E. H. (1999). Wheat: Ecology and Physiology of Yield Determination Haworth Press Technology and Industrial. 322-323.

Smith, A. E. (1995). *Handbook of Weed Management Systems.* Marcel Dekker.

Smith, E. H., and Whitman, R. C. (1992). *Field Guide to Structural Pests.* Dunn Loring, VA: National Pest Management Association.

Sogbesan, A. O., Olowosegun, T., and Ibiyo, L. M. (2005). Aquaculture Potentials and Investment Opportunity in Shrimps and Prawns Farming in Nigeria. *In Proceedings of the 19th Annual Conference of the Fisheries Society of Nigeria.* Ilorin, Nigeria: Fisheries Society of Nigeria (FISON).

Stansby, M. E. (1982). Properties of Fish Oils and their Application to Handling of Fish and to Nutritional and Industrial Use. In R. E. Martin, G. J. Flick, C. E. Hebard, and D. R. Ward, *Chemistry and Biochemistry of Marine Food Products* (pp. 75-95). Westport, C T: Avi Publishing Co.

Stathers, T. E., Denniff, M., and Golob, P. (2004). The Efficacy and Persistence of Diatomaceous Earth Admixed With Commodity Against Tropical Stored Products Research. *40,* 113-123.

Subasinghe, S. (1999). Chitin from Shell Waste-Health Benefits Over-Shadowing Industrial Areas. *Info Fish International, 3*(99), 58-65.

Subramanyam, B. H., and Hagstrum, D. W. (1995). Resistance Measurement and Management. In B. H. Subramanyam, and D. W. Hagstrum, *Integrated Management of Insects in Stored Products* (Subramanyam, B. and D.W. Hagstrum ed., pp. 331-398). New York: Marcel Decker.

Subramanyam, B., and Hagstrum, D. W. (2000). *Alternatives to Pesticides in Stored-Product IPM.* Norwell, MA. USA: Kluwer Academic Publishers.

Subramanyam, B., and Roesli, R. (2000). Inert Dust. In B. Subramanyam, and D. W. Hagstrum, *Alternatives to Pesticides in Stored Product Imp.* (pp. 321-398). Norwel: Wuwer Academic Publishers.

Suyono, G. I., and Naito, A. (1991). Effectiveness of Natural Substances, Ashes and Lime on the Soybean Stored Pest, *Callosobruchus analis* (F.). Palawija, Indonesia: Proceeding of Final Seminar of the Strengthening of Pioneering Research for Palawija Crops Production.

Vayias, B. J., and Athanassiou, C. G. (2004). Factors affecting the Insecticidal Efficacy of the Diatomaceous Earth Formulation SilicoSec against Adults and Larvae of the Confused Flour Beetle, *Tribolium confusum* Duval (Coleoptera: Tenebrionidae). *Journal of Crop Protection, 23*, 565-573.

Wang, X., and Xing, B. (2007). Importance of Structural Makeup of Biopolymers for Organic Contaminant Sorption. *Environmental Science Technology, 41*, 3559-3565.

Welch, J. J. (2010). The Island Rule and Deep-Sea Gastropods. Re- Examining the Evidence. *5*(1), e8776.

Zabbey, N., Erondu, E. S., and Hart, A. I. (2010). Nigeria and the Prospect of Shrimp Farming: Critical Issues. *Livestock Research for Rural Development, 22*, 198.

Zhai, X., and Hawkins, S. J. (2002). Interactions of Aquaculture and Waste Disposal in the Coastal Zone. *Journal of Ocean University of Qingdao, 1,* 8-12.

Appendix

MORTALITY

```
                              The SAS System            12:20 Thursday, May 11, 2017
23

                              The ANOVA Procedure

                           Class Level Information

                    Class         Levels    Values

                    SILICA             6    CRL D.E PRN PSD RHC STD

                    RATE               5    0.25 0.5 1 1.5 2

                    REP                3    1 2 3


                         Number of observations    90
```

The ANOVA Procedure

Dependent Variable: AV24hr AV24hr

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	29	49.79814628	1.71717746	31.11	<.0001
Error	60	3.31197659	0.05519961		
Corrected Total	89	53.11012288			

R-Square	CoeffVar	Root MSE	AV24hr Mean
0.937639	16.68799	0.234946	1.407874

Source	DF	Anova SS	Mean Square	F Value	Pr> F
SILICA	5	46.06855235	9.21371047	166.92	<.0001
RATE	4	2.22189019	0.55547255	10.06	<.0001
SILICA*RATE	20	1.50770375	0.07538519	1.37	0.1763

The ANOVA Procedure

Dependent Variable: AV48hr AV48hr

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	29	72.07103869	2.48520823	40.65	<.0001
Error	60	3.66831162	0.06113853		
Corrected Total	89	75.73935031			

R-Square	CoeffVar	Root MSE	AV48hr Mean
0.951567	13.22174	0.247262	1.870118

Source	DF	Anova SS	Mean Square	F Value	Pr> F
SILICA	5	69.73201995	13.94640399	228.11	<.0001
RATE	4	1.34791937	0.33697984	5.51	0.0008
SILICA*RATE	20	0.99109937	0.04955497	0.81	0.6914

The ANOVA Procedure

Dependent Variable: AV72hr AV72hr

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	29	69.47227639	2.39559574	39.26	<.0001
Error	60	3.66084288	0.06101405		
Corrected Total	89	73.13311927			

R-Square	CoeffVar	Root MSE	AV72hr Mean
0.949943	10.96330	0.247010	2.253064

Source	DF	Anova SS	Mean Square	F Value	Pr> F
SILICA	5	66.05378572	13.21075714	216.52	<.0001
RATE	4	0.93991601	0.23497900	3.85	0.0075
SILICA*RATE	20	2.47857467	0.12392873	2.03	0.0183

The ANOVA Procedure

Student-Newman-Keuls Test for AV24hr

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but

not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.0552

Number of Means	2	3	4	5	6
Critical Range	0.1716109	0.2061728	0.2267023	0.2412814	0.2525492

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	SILICA
A	2.92007	15	STD
B	1.51375	15	D.E
C	1.19196	15	RHC
C			
C	1.08420	15	PSD
C			
C	1.01063	15	PRN
D	0.72663	15	CRL

The ANOVA Procedure

Student-Newman-Keuls Test for AV48hr

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but

not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.061139

Number of Means	2	3	4	5	6
Critical Range	0.1806069	0.2169806	0.2385862	0.2539296	0.2657881

Means with the same letter are not significantly different.

SNK Grouping		Mean	N	SILICA
	A	3.21421	15	STD
	B	2.95677	15	D.E
	C	1.48732	15	PSD
	C			
D	C	1.40589	15	RHC
D				
D		1.22873	15	PRN
	E	0.92779	15	CRL

The ANOVA Procedure

Student-Newman-Keuls Test for AV72hr

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but

not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.061014

Number of Means	2	3	4	5	6
Critical Range	0.180423	0.2167596	0.2383432	0.2536709	0.2655174

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	SILICA
A	3.24037	15	STD
A			
A	3.20817	15	D.E
B	2.75122	15	PSD
C	1.75037	15	RHC
D	1.54688	15	PRN
E	1.02138	15	CRL

The ANOVA Procedure

Student-Newman-Keuls Test for AV24hr

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but
not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.0552

Number of Means	2	3	4	5
Critical Range	0.1566586	0.1882092	0.2069499	0.2202587

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	RATE
A	1.58312	18	2
A			
A	1.52490	18	1.5
A			
A	1.49391	18	1
B	1.22446	18	0.5
B			
B	1.21298	18	0.25

The ANOVA Procedure

Student-Newman-Keuls Test for AV48hr

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but
not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.061139

Number of Means	2	3	4	5
Critical Range	0.1648708	0.1980753	0.2177984	0.2318049

Means with the same letter are not significantly different.

SNK Grouping		Mean	N	RATE
	A	2.01727	18	2
	A			
	A	1.98013	18	1.5
	A			
B	A	1.89333	18	1
B				
B		1.75527	18	0.5
B				
B		1.70459	18	0.25

The ANOVA Procedure

Student-Newman-Keuls Test for AV72hr

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but

not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.061014

Number of Means	2	3	4	5
Critical Range	0.1647029	0.1978735	0.2175766	0.2315688

Means with the same letter are not significantly different.

SNK Grouping		Mean	N	RATE
	A	2.36942	18	2
	A			
	A	2.32072	18	1
	A			
	A	2.30990	18	1.5
	A			
B	A	2.16318	18	0.25
B				
B		2.10210	18	0.5

The ANOVA Procedure

Level of SILICA	Level of RATE	N	AV24hr Mean	AV24hr Std Dev	AV48hr Mean	AV48hr Std Dev	AV72hr Mean	AV72hr Std Dev
CRL	0.25	3	0.70710678	0.00000000	0.87965281	0.29885849	1.22130082	0.51248069
CRL	0.5	3	0.80473785	0.16910198	0.97728388	0.25956563	1.04044011	0.35528376
CRL	1	3	0.70710678	0.00000000	0.80473785	0.16910198	1.00000000	0.00000000
CRL	1.5	3	0.70710678	0.00000000	0.97728388	0.25956563	0.94280904	0.40824829
CRL	2	3	0.70710678	0.00000000	1.00000000	0.00000000	0.90236893	0.16910198
D.E	0.25	3	1.14982991	0.12975651	2.63815848	0.24531558	3.13207222	0.18757787
D.E	0.5	3	1.28790110	0.10938980	2.82472615	0.17715334	3.18764923	0.09131565
D.E	1	3	1.73896464	0.46260457	3.02662998	0.09626222	3.24037035	0.00000000
D.E	1.5	3	1.53429317	0.46788537	3.08001042	0.14249104	3.24037035	0.00000000
D.E	2	3	1.85776262	0.27032769	3.21433945	0.04508684	3.24037035	0.00000000
PRN	0.25	3	0.94280904	0.40824829	1.04044011	0.35528376	1.26756012	0.58304119
PRN	0.5	3	0.80473785	0.16910198	1.04044011	0.35528376	1.31893189	0.37500399
PRN	1	3	1.04044011	0.35528376	1.26862790	0.29304415	1.73896464	0.46260457
PRN	1.5	3	1.04044011	0.35528376	1.33178413	0.29920987	1.52549707	0.09637435
PRN	2	3	1.22474487	0.00000000	1.46234084	0.20576415	1.88342718	0.42314665
PSD	0.25	3	1.04044011	0.35528376	1.19371294	0.33552066	2.44538902	0.17351883
PSD	0.5	3	0.80473785	0.16910198	1.21298614	0.20735699	2.19375862	0.17645022
PSD	1	3	1.07491496	0.12975651	1.46985532	0.09637435	2.79655146	0.13765859
PSD	1.5	3	1.27614237	0.23914631	1.73867886	0.68227102	3.13207222	0.18757787

PSD	2	3	1.22474487	0.00000000	1.82136721	0.15470054	3.18830856	0.04508684
RHC	0.25	3	0.90236893	0.16910198	1.28790110	0.10938980	1.67236435	0.23408588
RHC	0.5	3	1.00000000	0.00000000	1.28790110	0.10938980	1.63144282	0.08712907
RHC	1	3	1.46234084	0.20576415	1.57580107	0.15898584	1.90806661	0.19728834
RHC	1.5	3	1.35105733	0.10938980	1.51264484	0.26049645	1.77831010	0.08012345
RHC	2	3	1.24401694	0.42264973	1.36519119	0.45208354	1.76168075	0.30776841
STD	0.25	3	2.53529724	0.32924442	3.18764923	0.09131565	3.24037035	0.00000000
STD	0.5	3	2.64462462	0.09455655	3.18830856	0.04508684	3.24037035	0.00000000
STD	1	3	2.93971064	0.19274870	3.21433945	0.04508684	3.24037035	0.00000000
STD	1.5	3	3.24037035	0.00000000	3.24037035	0.00000000	3.24037035	0.00000000
STD	2	3	3.24037035	0.00000000	3.24037035	0.00000000	3.24037035	0.00000000

PROGENY EMRGENCE/GRAIN DAMAGE

The ANOVA Procedure

Class Level Information

Class	Levels	Values
SILICA	6	CRL D.E PRN PSD RHC STD
RATE	5	0.25 0.5 1 1.5 2
REP	3	1 2 3

Number of observations 90

The ANOVA Procedure

Dependent Variable: AV40DAYS AV40DAYS

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	29	14.30381888	0.49323513	2.51	0.0013
Error	60	11.76850865	0.19614181		
Corrected Total	89	26.07232753			

R-Square	CoeffVar	Root MSE	AV40DAYS Mean
0.548621	41.71845	0.442879	1.061590

Source	DF	Anova SS	Mean Square	F Value	Pr> F
SILICA	5	12.00828558	2.40165712	12.24	<.0001
RATE	4	0.37711421	0.09427855	0.48	0.7498
SILICA*RATE	20	1.91841909	0.09592095	0.49	0.9610

The ANOVA Procedure

Dependent Variable: AV80DAYS AV80DAYS

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	29	16.47437942	0.56808205	3.94	<.0001
Error	60	8.66067894	0.14434465		
Corrected Total	89	25.13505836			

R-Square	CoeffVar	Root MSE	AV80DAYS Mean
0.655434	35.79956	0.379927	1.061262

Source	DF	Anova SS	Mean Square	F Value	Pr> F
SILICA	5	13.40210715	2.68042143	18.57	<.0001
RATE	4	0.74849788	0.18712447	1.30	0.2817
SILICA*RATE	20	2.32377439	0.11618872	0.80	0.6978

The ANOVA Procedure

Dependent Variable: graindamageAVgraindamageAV

Source	DF	Sum of Squares	Mean Square	F Value	Pr> F
Model	29	65.34349972	2.25322413	11.29	<.0001
Error	60	11.97853834	0.19964231		
Corrected Total	89	77.32203806			

R-Square	CoeffVar	Root MSE	graindamageAV Mean
0.845082	25.46057	0.446814	1.754923

Source	DF	Anova SS	Mean Square	F Value	Pr> F
SILICA	5	46.14840546	9.22968109	46.23	<.0001
RATE	4	9.30515053	2.32628763	11.65	<.0001
SILICA*RATE	20	9.88994373	0.49449719	2.48	0.0036

The ANOVA Procedure

Student-Newman-Keuls Test for AV40DAYS

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but

not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.196142

Number of Means	2	3	4	5	6
Critical Range	0.3234908	0.3886409	0.4273394	0.4548214	0.4760616

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	SILICA
A	1.8460	15	PRN
B	1.0245	15	PSD
B			
B	0.9675	15	CRL
B			
B	0.9611	15	D.E
B			
B	0.8633	15	RHC
B			
B	0.7071	15	STD

The ANOVA Procedure

Student-Newman-Keuls Test for AV80DAYS

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.144345

Number of Means	2	3	4	5	6
Critical Range	0.2775091	0.3333986	0.3665964	0.390172	0.4083931

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	SILICA
A	1.7421	15	PRN
B	1.3850	15	CRL
C	1.0411	15	PSD
C			
C	0.7657	15	D.E
C			
C	0.7266	15	RHC
C			
C	0.7071	15	STD

The ANOVA Procedure

Student-Newman-Keuls Test for graindamageAV

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but

not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.199642

Number of Means	2	3	4	5	6
Critical Range	0.3263647	0.3920935	0.4311359	0.458862	0.4802909

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	SILICA
A	2.7983	15	PRN
B	2.2591	15	PSD
B			
B	2.1933	15	CRL
C	1.3278	15	RHC
C			
C	1.2439	15	D.E
D	0.7071	15	STD

The ANOVA Procedure

Student-Newman-Keuls Test for AV40DAYS

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but
not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.196142

Number of Means	2	3	4	5
Critical Range	0.2953054	0.3547789	0.3901057	0.4151932

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	RATE
A	1.1753	18	1.5
A			
A	1.0730	18	0.5
A			
A	1.0596	18	0.25
A			
A	1.0121	18	1
A			
A	0.9879	18	2

The ANOVA Procedure

Student-Newman-Keuls Test for AV80DAYS

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but

not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.144345

Number of Means	2	3	4	5
Critical Range	0.25333	0.3043499	0.3346552	0.3561767

Means with the same letter are not significantly different.

SNK Grouping	Mean	N	RATE
A	1.1818	18	2
A			
A	1.1129	18	0.5
A			
A	1.0967	18	1
A			
A	0.9854	18	0.25
A			
A	0.9295	18	1.5

The ANOVA Procedure

Student-Newman-Keuls Test for graindamageAV

NOTE: This test controls the Type I experimentwise error rate under the complete null hypothesis but

not under partial null hypotheses.

Alpha	0.05
Error Degrees of Freedom	60
Error Mean Square	0.199642

Number of Means	2	3	4	5
Critical Range	0.2979288	0.3579308	0.3935714	0.4188818

Means with the same letter are not significantly different.

SNK Grouping		Mean	N	RATE
	A	2.2053	18	0.25
	A			
B	A	1.9551	18	1
B				
B		1.8335	18	0.5
	C	1.4220	18	2
	C			
	C	1.3587	18	1.5

The ANOVA Procedure

Level of SILICA	Level of RATE	N	AV40DAYS Mean	AV40DAYS Std Dev	AV80DAYS Mean	AV80DAYS Std Dev	graindamageAV Mean	graindamageAV Std Dev
CRL	0.25	3	1.05219884	0.29885849	1.44868840	0.59325615	2.34815457	0.47880602
CRL	0.5	3	0.97728388	0.25956563	1.58055246	0.50277318	1.98937293	0.25217658
CRL	1	3	0.87965281	0.29885849	1.21298614	0.20735699	2.36533370	0.32832105
CRL	1.5	3	1.04875479	0.59175171	1.21298614	0.20735699	2.10677281	0.30374739
CRL	2	3	0.87965281	0.29885849	1.46985532	0.09637435	2.15688787	0.52129848
D.E	0.25	3	1.04044011	0.35528376	0.80473785	0.16910198	1.86180732	0.22474487
D.E	0.5	3	0.80473785	0.16910198	0.70710678	0.00000000	1.35105733	0.10938980
D.E	1	3	0.87965281	0.29885849	0.70710678	0.00000000	1.22474487	0.00000000
D.E	1.5	3	1.17851130	0.40824829	0.80473785	0.16910198	0.97728388	0.25956563
D.E	2	3	0.90236893	0.16910198	0.80473785	0.16910198	0.80473785	0.16910198
PRN	0.25	3	1.58055246	0.50277318	1.19264516	0.60530677	2.57652399	0.20563602
PRN	0.5	3	2.04674027	0.84633408	1.99849647	0.50893788	3.07403896	0.27463920
PRN	1	3	2.09453267	1.08138770	2.15070152	0.24844411	3.61264115	0.41621612
PRN	1.5	3	2.09604085	0.95389682	1.34009881	0.55335593	2.04354953	0.48565212
PRN	2	3	1.41202266	0.71364418	2.02834789	1.15269565	2.68483694	0.96823339
PSD	0.25	3	1.07491496	0.12975651	1.05219884	0.29885849	3.32421778	0.65143247
PSD	0.5	3	0.90236893	0.16910198	0.97728388	0.25956563	2.48541688	0.85676973
PSD	1	3	0.70710678	0.00000000	1.09501409	0.67187516	2.50189481	0.33284157
PSD	1.5	3	1.21676051	0.88274616	0.80473785	0.16910198	1.51264484	0.26049645
PSD	2	3	1.22130082	0.51248069	1.27614237	0.74645225	1.47140452	1.32380252

RHC	0.25	3	0.90236893	0.16910198	0.70710678	0.00000000	2.41421356	0.50730594
RHC	0.5	3	1.00000000	0.00000000	0.70710678	0.00000000	1.39384685	0.29289322
RHC	1	3	0.80473785	0.16910198	0.70710678	0.00000000	1.31893189	0.37500399
RHC	1.5	3	0.80473785	0.16910198	0.70710678	0.00000000	0.80473785	0.16910198
RHC	2	3	0.80473785	0.16910198	0.80473785	0.16910198	0.70710678	0.00000000
STD	0.25	3	0.70710678	0.00000000	0.70710678	0.00000000	0.70710678	0.00000000
STD	0.5	3	0.70710678	0.00000000	0.70710678	0.00000000	0.70710678	0.00000000
STD	1	3	0.70710678	0.00000000	0.70710678	0.00000000	0.70710678	0.00000000
STD	1.5	3	0.70710678	0.00000000	0.70710678	0.00000000	0.70710678	0.00000000
STD	2	3	0.70710678	0.00000000	0.70710678	0.00000000	0.70710678	0.00000000

SAMARU DAILY WEATHER REPORT: 2015

Table A1: Monthly laboratory temperature and relative humidity within the storage Periods of 1st Experiment

			% RELATIVE HUMIDITY		AIR TEMPERATURE (0C)	
JDAY	MONTH	DATE	10 a.m	4 p.m	Max	Min
1	March	1	11	10	34	18
2	March	2	9	5	34	19
3	March	3	7	12	34	17
4	March	4	11	8	33	18
5	March	5	14	15	34	18
6	March	6	17	15	35	20
7	March	7	12	16	39	19
8	March	8	15	19	39	19
9	March	9	13	15	40	19
10	March	10	13	12	39	20
11	March	11	9	14	38	21
12	March	12	14	16	35	20
13	March	13	13	12	34	19
14	March	14	7	15	36	20
15	March	15	11	17	38	21
16	March	16	11	16	35	24
17	March	17	9	7	36	23
18	March	18	13	9	39	22
19	March	19	14	11	34	23
20	March	20	40	23	40	24
21	March	21	24	16	41	20
22	March	22	33	13	41	25
23	March	23	52	16	40	25
24	March	24	50	24	38	26
25	March	25	51	31	33	28
26	March	26	82	49	32	20
27	March	27	30	38	35	23
28	March	28	9	7	37	21
29	March	29	11	9	35	20
30	March	30	11	8	34	20
31	March	31	18	12	30	23

JDAY	MONTH	DATE	% RELATIVE HUMIDITY		AIR TEMPERATURE (0C)	
			10 a.m	4 p.m	Max	Min
1	April	1	12	16	33	23
2	April	2	11	13	35	22
3	April	3	10	9	36	25
4	April	4	24	6	37	20
5	April	5	16	9	38	21
6	April	6	52	35	38	21
7	April	7	16	24	40	20
8	April	8	58	12	40	24
9	April	9	61	33	37	25
10	April	10	63	42	37	23
11	April	11	15	2	32	26
12	April	12	16	5	32	23
13	April	13	14	6	29	20
14	April	14	7	10	33	20
15	April	15	7	9	32	20
16	April	16	6	8	29	18
17	April	17	6	10	31	23
18	April	18	9	8	38	23
19	April	19	8	9	36	20
20	April	20	8	11	37	20
21	April	21	8	7	38	23
22	April	22	11	11	39	20
23	April	23	7	10	40	20
24	April	24	17	5	37	20
25	April	25	39	7	39	22
26	April	26	10	11	38	21
27	April	27	19	12	39	23
28	April	28	8	7	39	20
29	April	29	41	7	39	20
30	April	30	38	10	40	20

JDAY	MONTH	DATE	% RELATIVE HUMIDITY		AIR TEMPERATURE (0C)	
			10 a.m	4 p.m	Max	Min
1	May	1	42	19	40	23
2	May	2	45	21	41	24
3	May	3	41	17	40	26
4	May	4	46	15	39	26
5	May	5	53	26	33	24
6	May	6	48	55	40	23
7	May	7	48	16	41	25
8	May	8	59	7	38	26
9	May	9	51	22	39	25
10	May	10	48	58	37	26
11	May	11	58	58	38	22
12	May	12	46	34	40	24
13	May	13	45	14	40	20
14	May	14	46	15	38	27
15	May	15	56	21	37	24
16	May	16	48	22	38	26
17	May	17	23	24	40	25
18	May	18	61	20	39	26
19	May	19	55	16	33	25
20	May	20	54	34	37	22
21	May	21	60	44	38	25
22	May	22	48	49	37	25
23	May	23	65	34	33	25
24	May	24	60	36	36	23
25	May	25	54	30	39	25
26	May	26	58	32	38	24
27	May	27	65	29	35	24
28	May	28	43	33	39	25
29	May	29	57	29	30	25
30	May	30	74	59	33	20
31	May	31	71	38	32	20

JDAY	MONTH	DATE	% RELATIVE HUMIDITY		AIR TEMPERATURE (0C)	
			10 a.m	4 p.m	Max	Min
1	June	1	82	54	33	18
2	June	2	77	41	33	20
3	June	3	77	51	32	21
4	June	4	68	57	30	20
5	June	5	65	58	35	20
6	June	6	72	42	29	24
7	June	7	67	60	33	18
8	June	8	76	55	29	23
9	June	9	80	77	29	21
10	June	10	73	57	35	24
11	June	11	70	35	34	25
12	June	12	53	46	34	23
13	June	13	60	43	35	23
14	June	14	70	32	36	22
15	June	15	79	53	34	22
16	June	16	68	66	32	21
17	June	17	58	66	33	24
18	June	18	71	56	35	22
19	June	19	80	57	34	23
20	June	20	76	55	34	21
21	June	21	76	62	31	23
22	June	22	72	68	31	23
23	June	23	77	57	34	24
24	June	24	63	67	30	24
25	June	25	84	54	33	20
26	June	26	78	76	28	22
27	June	27	78	78	32	22
28	June	28	70	65	33	24
29	June	29	75	65	34	23
30	June	30	71	56	34	24

Table A2: Average monthly laboratory temperature and relative humidity within the storage Periods of 1st Experiment

Month/Year	Temperature ^oC		Relative Humidity (%)
	Min	Max	
March	21.13	36.19	36.26
April	21.53	36.27	32.70
May	24.19	37.35	82.42
June	22.13	32.63	129.17
Average	22.25	35.61	70.14

Table A3: Monthly laboratory temperature and relative humidity within the storage Periods of 2nd Experiment

JDAY	MONTH	DATE	% RELATIVE HUMIDITY		AIR TEMPERATURE (0C)	
			10 a.m	4 p.m	Max	Min
1	July	1	83	65	29	18
2	July	2	77	68	33	22
3	July	3	76	63	32	18
4	July	4	71	77	32	20
5	July	5	70	67	32	19
6	July	6	83	59	29	21
7	July	7	84	67	31	21
8	July	8	83	61	28	19
9	July	9	81	96	29	20
10	July	10	79	93	30	21
11	July	11	73	70	32	22
12	July	12	68	64	32	21
13	July	13	79	64	33	20
14	July	14	78	46	30	21
15	July	15	69	82	31	20
16	July	16	74	78	30	21
17	July	17	78	57	29	21
18	July	18	94	84	26	19
19	July	19	76	86	29	19
20	July	20	71	82	33	21
21	July	21	75	47	33	20
22	July	22	76	48	31	21
23	July	23	86	67	31	21
24	July	24	76	71	32	18
25	July	25	91	59	26	19
26	July	26	86	82	31	21
27	July	27	84	63	30	18
28	July	28	85	67	31	21
29	July	29	86	59	31	21
30	July	30	78	56	33	18

JDAY	MONTH	DATE	% RELATIVE HUMIDITY		AIR TEMPERATURE (0C)	
			10 a.m	4 p.m	Max	Min
1	August	1	77	75	30	20
2	August	2	86	71	30	21
3	August	3	88	62	29	19
4	August	4	81	75	31	19
5	August	5	79	66	31	19
6	August	6	79	71	30	19
7	August	7	82	96	31	19
8	August	8	83	80	28	20
9	August	9	81	74	28	20
10	August	10	80	94	31	18
11	August	11	80	62	28	21
12	August	12	83	60	30	19
13	August	13	82	65	31	21
14	August	14	78	65	33	21
15	August	15	78	60	28	18
16	August	16	76	74	29	18
17	August	17	82	71	28	20
18	August	18	82	77	28	20
19	August	19	89	95	29	20
20	August	20	85	80	28	20
21	August	21	86	92	30	18
22	August	22	70	71	30	20
23	August	23	87	72	30	19
24	August	24	88	69	29	19
25	August	25	77	73	32	19
26	August	26	85	55	32	19
27	August	27	80	61	28	18
28	August	28	89	68	28	21
29	August	29	83	70	30	19
30	August	30	81	67	30	21

JDAY	MONTH	DATE	% RELATIVE HUMIDITY		AIR TEMPERATURE (0C)	
			10 a.m	4 p.m	Max	Min
1	September	1	71	66	30	24
2	September	2	80	58	30	26
3	September	3	77	71	32	27
4	September	4	72	76	31	26
5	September	5	82	61	31	24
6	September	6	77	64	33	26
7	September	7	84	62	32	26
8	September	8	82	63	30	24
9	September	9	79	66	33	26
10	September	10	80	90	28	22
11	September	11	76	69	31	25
12	September	12	80	62	31	22
13	September	13	75	60	32	26
14	September	14	80	66	31	24
15	September	15	75	65	29	25
16	September	16	83	67	31	25
17	September	17	71	61	32	27
18	September	18	74	65	34	29
19	September	19	76	46	33	26
20	September	20	72	57	33	26
21	September	21	82	65	33	27
22	September	22	73	65	31	24
23	September	23	75	84	33	26
24	September	24	83	84	33	25
25	September	25	72	56	34	29
26	September	26	72	64	33	27
27	September	27	85	56	32	25
28	September	28	71	59	31	25
29	September	29	82	60	30	24

JDAY	MONTH	DATE	% RELATIVE HUMIDITY		AIR TEMPERATURE (0C)	
			10 a.m	4 p.m	Max	Min
1	October	1	75	60	33	21
2	October	2	74	64	34	21
3	October	3	87	62	29	18
4	October	4	81	69	31	22
5	October	5	73	99	33	19
6	October	6	69	61	34	19
7	October	7	72	65	33	20
8	October	8	86	55	30	21
9	October	9	84	68	32	21
10	October	10	60	83	32	21
11	October	11	78	64	32	21
12	October	12	75	60	33	21
13	October	13	73	82	33	19
14	October	14	70	42	34	19
15	October	15	82	42	33	19
16	October	16	63	52	34	21
17	October	17	55	90	34	21
18	October	18	63	56	34	17
19	October	19	77	47	33	18
20	October	20	39	79	33	19
21	October	21	40	32	34	14
22	October	22	47	26	34	14
23	October	23	61	30	33	17
24	October	24	25	29	34	16
25	October	25	22	59	33	15
26	October	26	29	22	34	12
27	October	27	32	26	35	20
28	October	28	43	28	35	14
29	October	29	24	36	35	17
30	October	30	25	25	34	14
31	October	31	28	27	35	14

Table A4: Average monthly laboratory temperature and relative humidity within the storage Periods of 2nd Experiment

Month/Year	Temperature ^{o}C		Relative Humidity (%)
	Min	Max	
July	20.07	30.63	147.27
August	19.50	29.67	154.27
September	25.45	31.62	142.38
October	18.23	33.23	111.35
Average	20.81	31.29	138.82