EVALUATION OF THE EFFICACY OF INSECTICIDES IN THE CONTROL OF THE LARGER GRAIN BORER (*Prostephanus truncatus*) ON MAIZE (*Zea mays* L.) IN ZIMBABWE

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN CROP PRODUCTION

BY

KUDZAI SIGAUKE

FACULTY OF AGRICULTURE AND NATURAL RESOURCES

AFRICA UNIVERSITY

MUTARE

MAY 2014

DECLARATION

I……………………………………………do hereby declare that this work is my original work undertaken at Africa University, Mutare, Zimbabwe in partial fulfillment of the requirements for the degree of Master of Science in Crop Production and has not been submitted to any university for the award of any other degree.

……..………………………………

Student's signature

Date……………………………….

Approved for submission by:

……………………………………

Name of Supervisor

……………………………………

Signature

Date………………………………

ABSTRACT

The Larger Grain Borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) is an important storage pest of maize which causes substantial damage on stored maize thus affecting quantity and quality of maize in the smallholder and commercial sector. A study was conducted to determine the impact of *P. truncatus* on maize varieties and the efficacy of insecticides and cultural methods used by farmers in Zimbabwe. The objectives were; to identify larger grain borer tolerant maize varieties that can be grown in LGB infested areas, to evaluate the effectiveness of the insecticides used by seed companies in Zimbabwe and to evaluate the effectiveness of registered insecticides and wood-ash on reducing damage caused by *P. truncatus* on stored maize. Two laboratory experiments were conducted on the efficacy of dust insecticide protectants used by farmers and using Msasa wood-ash on the white maize variety SC403 and the yellow maize variety PHB30D50. A third laboratory experiment was a bioassay on grain protectants used by seed companies namely; Apron star (Prime Seeds) and Superguard 50EC used by ARDA, Pioneer and Pannar. A fourth laboratory experiment was a bioassay on the Manyika landrace using Actelic Gold Chirindamatura Dust grain protectant. Data on grain weight loss (g); frass weight (g); LGB mortality (%) and LGB population counts was recorded. Grain weight and frass weight was subjected to analysis of variance and comparisons between treated and untreated samples were calculated using the t-test statistic. MINITAB version 13 and GENSTAT version 14.1 statistical packages were used. Results for experiments one and two showed that Actelic Gold Chirindamatura Dust, Shumba Super Dust Grain Protectant, Chikwapuro Grain Protectant and Superguard Dust Insecticide were effective against LGB. The differences among all four insecticides were not significant ($p>0.05$) at 28, 56 and 84 days for both yellow and white maize. Wood ash was not effective as an abrasive to control *P. truncatus*. For experiment three, Apron star and Superguard 50EC were effective insecticides in controlling and managing LGB, although Superguard 50EC in PAN 53 was not effective at all three dates. Farmers are encouraged to use Actelic Gold Chirindamatura Dust, Superguard Dust Insecticide, Chikwapuro Grain Protectant and Shumba Super Dust Grain Protectant combined with other IPM measures such as early harvesting and storage hygiene to manage the larger grain borer pest. Seed companies need to treat the seed using effective grain protectants such as Actelic Gold Chirindamatura Dust and Apron star and implement IPM measures to reduce LGB infestation of seed in storage.

ACKNOWLEDGEMENTS

I wish to concede my greatest appreciation to my supervisor Dr. W. Manyangarirwa of Africa University for his contributions towards the research project.

The execution of the project was dependent on the support and encouragement of my parents, henceforth; I wish to extend exceptional credit, recognition and appreciation to Mr. and Mrs. D. Sigauke, for financial, intellectual and divine support.

Earnest, divine and cordial assistance through-out the research, from Ms F.B. Nyatanga and Ms L. Nyatanga is greatly appreciated. Academic and physical work was made bearable through their assistance both intellectually and physically.

Special mention goes to lecturers and staff of Africa University namely; Mr. T.A. Mtaita, L. Mr Kies, Mr. T. Masaka, and Mr. J. Tabarira, Mr N. Rufu, (Pannar), Mr G. Nyamutowera, (Pioneer), Mr Mukiwa (ARDA) and Mr M. Gascoigne, (Prime Seeds).

Correct citation: Sigauke, K. 2014. Evaluation of the efficacy of insecticides in the control of the Larger Grain Borer (*Prostephanus truncatus*) on maize (*Zea mays* .L) in Zimbabwe. M.Sc. thesis, Africa University.

DEDICATION

This work is dedicated to the Sigauke Family. May God continue blessing you abundantly.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS

AGRITEX	Agricultural Technical and Extension Services
LGB	Larger Grain Borer
IPM	Integrated Pest Management
EIL	Economic Injury Level

CHAPTER 1

1.0 INTRODUCTION

Maize (*Zea mays* L.) is an important crop in African countries as it plays a major role as a staple diet. Maize is a domesticated crop in the Poaceae family. It is grown in many countries in different continents namely Africa, Asia, Australia and America. Maize is produced and stored extensively and intensively in African countries (Abate *et al*., 2000) which include Zimbabwe, Malawi, Zambia, Tanzania and South Africa. Maize is grown for different purposes and uses depending on maize type and such uses include: producing stock feeds, producing human food and ethanol for engine fuel (OGTR, 2008). Maize is affected by many weeds, insect pests and diseases and among the most important pests of maize, the larger grain borer (LGB) (*Prostephanus truncatus)* is included (Tefera *et al*., 2010). Larger grain borer is a pest that attacks maize both in the field and in storage and causes devastating effects (Rugumamu, 2005). Many Integrated Pest Management (IPM) methods to control and manage the pest have been incorporated of which some have been successful and some have not been successful as the pest continues to spread across Africa. Methods that have been incorporated include the use of solar dryers (Seidu *et al*., 2010), use of abrasives such as diatomaceous earth and wood-ash as grain protectants (Stathers, 2003), insecticides and varietal tolerance (Rugumamu, 2006). *P. truncatus* continues to be a problem as it has spread across Africa and has been mapped out (Nyagwaya *et al*., 2010) in the predicted potential invasion areas in Zimbabwe

(Rwegwasira *et al*., 2003), thus the importance of studying the pest and finding solutions to curb the problems caused by this pest in Zimbabwe.

1.1 Statement of the problem

Prostephanus truncatus is one of the most important pests of stored maize in Zimbabwe (CABI, 2010) and is causing yield losses and yield quality reduction in stored maize. In some cases, field maize is also attacked by LGB as stated by reports made in areas covering the northern part of Zimbabwe, southern-east part of Zimbabwe and some parts of the eastern highlands (Rwegwasira *et al*., 2003; Nyagwaya *et al*., 2010). These reports have been confirmed by surveys done on the occurrence, distribution and management of LGB in Zimbabwe by Nyagwaya *et al*., (2010). Due to the devastating impact of LGB on maize, there is the need to assess the impact of LGB of maize attack on stored maize and to come up with solutions to curb the problems caused by *Prostephanus truncatus*.

1.2 Justification of study

LBG is a serious pest of stored maize and it can also be a serious problem even before harvest as the pest can attack maize in the field (Sallam, 2008). *Prostephanus truncatus* tunnels into the grains of maize, either directly through the apex of the cobs or by directly burrowing through the husk to access the cob leaving mealy-meal-like dust. Losses in weight caused by LGB can be as high as 34% (GASGA, 1998). LGB populations are reportedly spreading from the borders in the northern part, southern east part and parts of the eastern parts of Zimbabwe (Nyagwaya *et al*., 2010). The attack of LGB on stored maize and the risk of maize yield losses are henceforth inevitable in the invaded areas.

There is therefore a need to assess the impact of the pest on maize in the invaded areas and set measures or solutions to curb the problems caused by larger grain borer.

Varietal resistance can be utilized by farmers who grow maize. Maize varieties may have some degree of tolerance to LGB attack due to strong seed coats that are hard for the pest to penetrate. Such varieties will take longer to be significantly damaged by the pest (Li, 1988). There is therefore the need to test varieties used in the LGB prominent areas of Zimbabwe for tolerance to LGB attack. Since farmers may utilize chemical control, there is need to test for effectiveness of chemicals and recommendations on rotational use of these chemicals. IPM is to be considered in the trial analysis to reduce chances of LGB developing resistance to registered insecticides.

1.3 Objectives

1. To identify Larger Grain Borer tolerant varieties of maize that can be grown in LGB infested areas.
2. To evaluate the effectiveness of the chemicals used by seed companies in Zimbabwe.
3. To evaluate the effectiveness of registered insecticides and wood ash on reducing damage caused by *Prostephanus truncatus* on stored maize

1.4 Hypotheses

1. There are significant levels of tolerance in the different maize varieties grown by farmers in Zimbabwe to LGB damage.

2. Among the seed dressing chemicals used by different seed companies there is one which is more effective against *Prostephanus truncatus*.
3. There are significant levels of effectiveness among registered insecticides for *Prostephanus truncatus*.

CHAPTER 2

2.0 LITERATURE REVIEW

Maize (*Zea mays L.*) is one of the most important food crops in the world, with the world total for maize production estimated at 844,404,181 metric tonnes (FAOSTAT, 2014). Most African countries produce maize at commercial levels. These countries include: Zimbabwe (1,192,400mt), Tanzania (4,475,420mt), Zambia (2,795,480mt), South Africa (12,815,000mt), Kenya (3,222,000mt), Malawi (3,800,000mt) and Mozambique (1,878,000) (FAOSTAT, 2014). Maize is also produced and consumed either directly or indirectly by many other countries in different continents. Maize contains low protein which is 8-11% of the kernel and the chemical composition of white and yellow maize is considered to be the same (Bull, 1928). Maize is one of the many important energy sources for direct consumption considering that the starchy components take about 70% of the maize kernel (Figure 2.1).

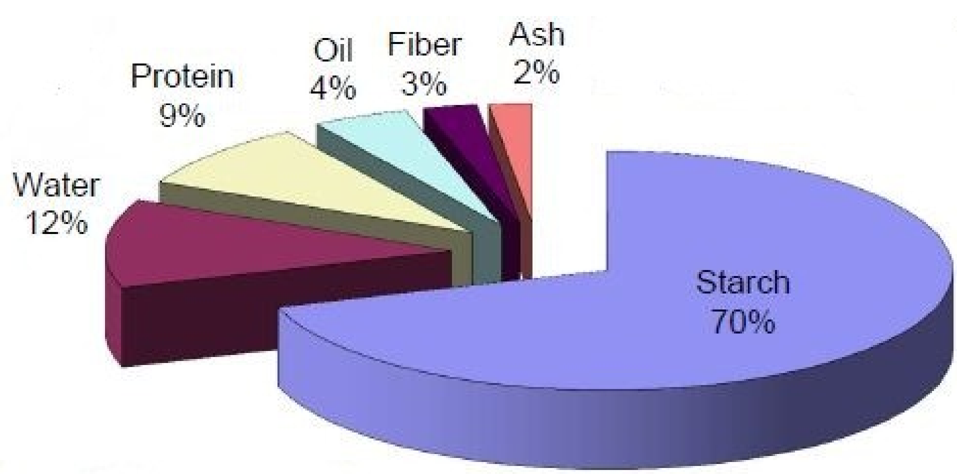

Figure 2. 1 Maize kernel nutrient composition. Source: Wastayn (2013).

Maize has variable cob size, kennel size, colour and shape. Maturity and growth habit ranges widely and both are dependent on the environment. Variable environments influence variable growth habit and maturity on the vast range of maize varieties. Maize is affected by a lot of insect pests and diseases. This particular project looks at the Larger Grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae), which is a member of a wood-boring family. It is widely reputable as a major pest of stored and field maize (Sallam, 2008). A single adult *P. truncatus* is capable of destroying energy of maize kernels which can be equated to a total of five maize kernels. LGB is native to meso-America (Hodges, 1986) and it has long been recognized as a destructive pest of stored maize.

2.1 Biology and Taxonomy of *P. truncatus.*

Prostephanus truncatus (Horn) (Coleoptera: Bostrichidae), commonly known as larger grain borer is in the kingdom animalia and phylum anthropoda. It is under the class, Insecta and order Coleoptera and the insects in this order are commonly recognized as beetles. It is found in the Bostrichidae family and subfamily Dinoderinae (Horn, 1878).

The body length of the adult grows up to 3.5 mm in length and the width is normally 1.5 mm (Birkinshaw and Hodges, 2000). LGB features such as; deflexed head, strong mandibles and a cylindrical body shape correspond to the xylophagous insects. Xylophagous comes from the term xylophagy which is an ecological term describing feeding habits of an animal whose primary diet consists of wood. Xylophagous insects are therefore insects that live in or on wood (Lakatos and Thuroczy, 2002). Larger grain borer can switch between woody and stordy substrates but this change can be impeded by either conditioned behavior or adaptation of the population of the gut symbiants for the substrate (Hill *et at.,*2002). Adult beetles burrow into maize kernels and leave round holes on maize kernels and significant quantities of dust. When tunneling, the large pronotum of *P.truncatus* protects the head and provides strong support for the mandibular muscles (Li, 1988). *P. truncatus* is capable of flying and an adult LGB beetle can fly up to an estimated distance of 25 km in 45 hours (Pike, 1993).

P. truncatus reproduces on maize grain and ears, dry cassava and other stored commodities (Tefera *et al*., 2010). LGB have higher reproductive rate compared to other grain storage pests and they have higher reproductive rate on cobs compared to loose grain (Makundi *et al.,* 2010). It undergoes the following stages in its life cycle: egg; three larval instar stages; and the adult. Adult females lay their eggs in batches of 20 and cover them with maize powder or powder of the infested commodity within the grain in chambers bored at right angles to the main tunnel. Egg oviposition begins 5-10 days after adult emergence (Bell and Watters, 1982). LGB has a lifetime fecundity of 300 eggs when reared on yellow maize. Fecundity and survival reduce in maize varieties that have flint kernels (Li, 1988). The eggs take 25 to 167 days to develop and this period is influenced by temperature. Temperatures of about 32ºC result in lesser days of development while low temperatures of about 18ºC influence a longer period of development. Larvae hatch from the eggs after three to seven days. Average larval period lasts about 16 days (Tefera *et al.,* 2010). The last larval stage makes a pupal case from fine powdery refuse and excrement of the larvae. The larvae have a white, fleshy, C-shaped body that has sparse hairs and its head is retracted into the prothorax.

2.2 Origin and distribution of *P. truncatus.*

The LGB was initially common in Mexico and parts of Central America where it is widespread and prevalent (Golob, 1988), and there it is known to be of minor economic importance. Contrary to Mexico and Central America, LGB is a pest of major economic importance in Africa. It has devastating effects on both smallholder and commercial production of agricultural production affecting crops in the field, stored grain and seed. The affected crops include maize and cassava among many. The pest has been well established for an estimated 35years in Africa (Rwegwasira *et al*, 2003).

P. truncatus is said to have been unintentionally introduced into Africa via Tanzania in the late 1970s through maize that was intended as aid at Urambo and Tabora refugee camps (Dunstan and Magazini, 1981). In West Africa, *P. truncatus* was first found in Togo in the early 1980s (Krall, 1984) and has now spread to over 18 countries and has become the most persistent and destructive pest with devastating effects on field and stored maize in Eastern, Western, Central and Southern Africa. LGB spread across and along African countries in a rather discrete trend covering sub-Saharan counties that include Kenya (1983), Burundi (1984), Malawi (1993), Rwanda (1993), Zambia (1993), Uganda (1997), Namibia (1998) and South Africa (1998); in Central, Eastern and Southern Africa; and Benin (1986), Guinea (1987), Ghana (1989), Burkina Faso (1991), Nigeria (1992) and Niger (1994) in Western Africa (Kasambala and Chinwada, 2011; Anon., 1998). In some of these countries, it has become a serious pest of stored maize and dried cassava. Zimbabwe has been added to the list of infested countries. This infestation was through maize imported into the country legally and illegally due to food shortages that were influenced by unprecedented droughts that affected the country in the years 2000-2003 (Rwegwasira *et al*, 2003).

The reports on the presence of the pest in Zimbabwe have been confirmed and the occurrence of the pest was mapped out. In Zimbabwe, *P.truncatus* is infesting from the borders as there are higher concentrations at the borders and areas proximal to the borders and lower concentrations away from the borders. There are higher concentrations of LGB in the northern regions compared to other regions. This is the part where Zimbabwe borders with Zambia (Nyagwaya *et al*., 2010). This then tallies with the fact pointed out in literature that a higher percentage of maize importations were from Zambia and Malawi (Rwegwasira *et al*, 2003). Zimbabwe's proximity to Malawi, Tanzania, South Africa and Zambia and the unprecedented regular droughts that affected the country necessitated grain importations. Mozambique and Zimbabwe were then put at high risk from the infestation of LGB pest. This pest is capable of self-flight and it is estimated that an adult can fly 25 km in 45 hours (Pike, 1993). Flight activity is initiated by a reduction in food quality and seasonality in tree growth, albeit in the case of Zimbabwe and Africa at large, the inter-continental and inter-regional trade in maize and other cereals have largely contributed to the spread of the pest (Golob, 1988). The existence of a well-established transport network, both road and rail across the country poses a risk of the pest spreading from the Mashonaland Provinces to the rest of the country.

2.3 *P. truncatus* host plants.

In Zimbabwe, alternative host plants for *P. truncatus* have been identified (Giles *et al*., 1995) and mapped out using specimens from the herbarium. Of the 22 LGB alternative host plants found in Kenya, 16 plant species were found to occur in Zimbabwe. The plants were found to exist across Zimbabwe and these were similar to those identified in Kenya, where the pest is already prevalent implying that the pest has high chances of proliferating in Zimbabwe. Some of these plant species that were found occurring in Zimbabwe are *Cassia siamea, Delonix regia, Euphobia tirucalli, Leucaena leucocephala* and *Prosopis pallida*. These species in particular are not naturally occurring in the agro-ecological regions of Zimbabwe. Confirmation of the existence of the plant species in the mapped out areas was done through surveys that were supported by using the global positioning system, GPS-315 (Magellan, 1999). The areas include Harare, Chitungwiza, Mazowe and areas along Harare-Bulawayo road (Nyagwaya *et al.*, 2010).

2.4 Impact of LGB on maize.

The larger grain borer is a serious pest of stored maize. It attacks maize on the cob, both before and after harvest by tunneling into the maize husks, cobs or grain leaving well defined round holes (Tefera *et al.*, 2010). The pest leaves frass as it tunnels. *P. truncatus* gain access to maize cobs through the top of the cob through which they gain entrance and access to the grain on the cob. The pest prefers grain on the cob rather than loose grain although this preference is not significant as the pest will still attack loose grain at devastating rates (Tefera *et al.,* 2010). However, LGB damage on maize cobs is greater than on loose grain (Makundi *et al.,* 2010). *P. truncatus* attack results in considerable losses in stored maize. Compared to other storage pests, larger grain borer burrows into maize kernels aggressively causing high grain damage resulting in substantial yield losses (Makundi, *et al.,* 2010). The feeding of large populations of *Sitophilus zeamais* can be exceeded by that of small populations of *Prostephanus truncatus*, henceforth, a combination of the two species can cause even more substantial losses in grain weight (Makundi, *et al.,* 2010). In East Africa, weight losses that have been observed and recorded are as high as 35% and these were observed after a period of only 3 to 6 months storage (Hodges *et al*., 1983; Muhihu and Kibata, 1985). The pest has managed to spread through the movement of infested maize from maize surplus to maize deficit areas, and by flight activity although flight activity is a minor factor (Omondi *et al.,* 2011). Despite that larger grain borer favours high temperatures and high relative humidity, it also tolerates dry conditions and much lower levels of humidity with low moisture contents that are at 9% (Haines, 1991) in contrast to many other storage pests. This means the LGB is a predominant storage pest, even where others exist, especially in dry conditions where proliferation of most storage pests is not favoured. *Prostephanus truncatus* (Horn) is able to cause substantial damage and losses to farm-stored maize (Hodges 1982).

2.5 LGB management using insecticides.

P. truncatus can be controlled using insecticides such as pyrethroids, organophosphates and neonocotinoids. Some of the known commercial product names of these insecticides are Superguard 50EC, Protect it, Chemutsi, Shumba Super Dust Grain Protectant, Chikwapuro Grain Protectant, Superguard Dust Insecticide and Actelic Gold Chirindamatura Dust (Nyagwaya *et al*., 2010). In Kenya, farmers have adopted the use of dust mixtures of 1.6% pirimiphos methyl (organophosphate) and permethrin (pyrethroid) at recommended rates to control LGB (Giles and Kibata, 1992). Pyrethroid toxicity decreases with an increase in temperature but with thiamethoxam and organophosphates, mortality of insect pests increases with increased temperatre. This could be because of the increased movement of insects with increasing temperature resulting in increased contact with the insecticide (Arthur *et al.,* 2004). Thiamethoxam is a new generation neonicotinoid which is highly toxic to stored product beetles on wheat and maize (Arthur *et al.,* 2004). Silica aerogels such as Gasil 23D and Aerosil 972 can also be effective insecticides (Barbosa *et al*., 1994). Studies have been done on pirimiphos methyl, malathion, fenvalerate, chlorpyrifos-methyl, permethrin, deltamethrin, (IR)-phenothrin and lindane. These have been seen to be effective in controlling LGB although synthetic pyrethroids were found to be more effective compared to organophosphorous compounds (Golob *et al.,* 1985). The degree of survival of an insect depends on the concentration of the chemical insecticide and the susceptibility of the individual insect species. With chemicals such as thiamethoxam, the longer the insect is exposed, the more likely it is to die (Arthur *et al.,* 2004), henceforth, less susceptible insect pests like LGB will still be affected by the chemical in time.

The use of phyto-bioactive extracts has been recommended and seen to be effective. Bioactive extracts from *Lantana camara* leaves and *Psidium guajava* have been found to be effective against *P. truncatus* and the phyto-bioactive extracts from these plants are environmentally friendly (Jean Pierre *et al*., 2013).

2.6 LGB management using biological control.

Biological control methods of pest control can be very effective. For *Prostephanus truncatus,* predation is a known biological control which can be used to manage the insect pest through the use of a known predator of the LGB beetle, the histerid beetle, *Teretriosoma nigrescens* Lewis (Markham *et al*., 1991). The *T. nigrescens* beetle is native to Central America (Markham *et al*., 1991) and was introduced to East and West Africa in a bid to control LGB populations. This measure has been effective with reference to the reducing populations of LGB in relation to the increasing populations of *T. nigrescens* (Borgemeister *et al.,* 2010). Although the predator has considerable effect on LGB, *T. nigrescens* does not have much effect on the insect pest where pesticide is used as it is susceptible to insecticides more than LGB (Golob *et al*., 1990). The adult immature stages of the *T. nigrescens* beetle feed on eggs and larvae of the LGB. *T. nigrescens* has a role to play in the management of LGB and it is able to reduce the density of the insect pest (Hodges, 1994)

2.7 LGB management using cultural practices.

Cultural methods and practices that can be used to control LGB include crop rotations, choice of tolerant varieties, field sanitation, use of abrasives such as diatomaceous earth and store hygene. Rotations can help break the life cycle of *P. truncatus* although it may not be as effective since the insect pest has a wide range of host plants on which it can find habitat and survive until the season the maize is planted (Giles *et al*., 1995; Nyagwaya *et al*., 2010). Varietal role can be very useful and it essentially helps manage LGB damages on stored maize. Varieties with flint kernels are damaged less compared to the dent kernel varieties (Rugumamu, 2006). Flint kernel varieties discourage LGB tunneling and oviposition into the maize kernels due to the high energy cost required to burrow into the kernels through a hard seed coat (Li, 1988). Good store hygiene is important in limiting LGB infestation by making sure the designated store rooms are clean and the maize to be stored is clean.

2.8 LGB management using host-plant resistance.

Host-plant resistance is an important alternative control technology that has been vastly ignored since the introduction and vast use of residual insecticides on stored grain (Throne and Eubanks, 2002). Maize resistance against LGB exists and can be expressed basing on three parameters namely, grain damage, powder production and the number of LGB recovered (Kumar, 2002). Host-plant resistance can be very useful in maintaining insect populations below economic injury level (EIL) and works best when combined with other control methods (Gudrups *et al.,* 2001). There are several resistance genotypes that can be utilized against LGB. In a study carried out by Kumar (2002), 19 landraces out of 105 were resistant against LGB and F2 of these exhibited high levels of resistance as they were not easily disintegrated into powder (Kumar, 2002). Some of the resistant genotypes are characteristic of high oil and protein content henceforth, this could be associated with resistance either directly or indirectly (Mwololo *et al.,* 2012). The presence of resistance genotypes against LGB attack and other coleopteran insect pests can be attributed to physical factors such as the hardness of the grain, biochemical traits and phenolic compounds, size of the kernel, husk protection, presence of anti-feedants and, ferulic and couamric acid (Gudrups *et al.,* 2001 and Mwololo *et al.,* 2012). A strategy that has been used to find germplasm for developing improved plant varieties is to test ancestral germplasm from progenitors of commercial varieties (Throne and Eubanks, 2002). An example of such is Tripsacorn, developed developed from Tiosinte (*Zea diploperennis*) and eastern gamagrass (*Tripsacum dactyloides*) (Throne and Eubanks, 2002). Tripsacorn kernels have a primitive defense mechanism of a hard fruit case that is difficult to grind although the kernels are susceptible once the fruit case has been opened. Some varieties of maize can be less suitable for egg production and development for some grain storage pests, henceforth there will be lower oviposition and longer laval development periods (Akob and Ewete, 2010). Susceptible varieties experience 9% – 45% loss when attacked by LGB depending on the time of infestation and the period of store, but when resistance genes are incorporated, losses can be reduced to 5% or less (Kumar, 2002). The presence of resistance genotypes suggest the possibility to develop improved maize hybrids that are resistant to LGB through manipulation of genes of the resistance genotypes (Mwololo *et al.,* 2012). A study done by Derera *et al* (2001) shows that is is possible to develop hybrids with improved non-preference resistance of F_2 grain where average parents of a hybrid with resistance genes contribute to non-preference resistance (Dererea *et al.,* 2001). Host-plant resistance is environmentally safe, economically feasible and socially acceptable (Kumar, 2002).

2.9 LGB management using integrated pest management (IPM).

Integrated Pest Management refers to broad-based approach to pest management that integrates cultural, biological and chemical control of pests with the aim to suppress pests below economic injury level (EIL) (Bajwa and Kogan, 2002; Ehler, 2006) while reducing negative impact on the environment (Jean-pierre *et al.,* 2013). Biological control of

P.truncatus can be utilized through introducing the *Teretriosoma nigrescens* beetle (Markam *et al.,* 1991). This has been done in Benin and Togo as a measure to control LGB. The predatory species preys on the larvae and egg stages of LGB. although the numbers of *T. nigrescens* increased considerably, accompanied with a decrease in LGB populations (Borgemeister *et al..,*2010). The ability of the LGB beetles to reproduce at exponential rates ensures survival of the insect pest. The use of biological methods therefore would be useful on a long term basis. Cultural practices such as rotations, abrasives and field hygiene is to be considered. Freezing for several days and heating for 24 hours can be effective in controlling LGB. Where suitable infrastructure exists, low oxygen and high carbon atmospheres can help control LGB. Chemical control can be incorporated and be used simultaneously with cultural and/or biological control and/or host plant resistance. Host-plant resistance is environmentally safe, economically feasible and socially acceptable, henceforth, it can be utilized as a method of IPM (Kumar, 2002). The use of synthetic insecticides such as thiamethoxam, deltamethrin, permethrin, pirimiphos methyl, fenitrothion and silica can be useful (Nyagwaya *et al*., 2010) although the use of phyto-bioactive extracts is much safer for the environment (Jean-Pierre *et al.,* 2013). The use of host plant resistance can in conjunction with other control methods to form IPM, would provide more substantial and long term results to maintain storage insect pests at acceptably low levels (Gudrups *et al.,* 2001). There are other methods that can be taken into consideration on the management and control of LGB. Thermal disinfection can be utilized to control and manage LGB. Stored grain insects are killed by exposure to 50 - 60ºC temperatures for a period of an hour or less, hence the use of solar driers and sun-drying (McFarlane, 1988). Phytosanitary measures can be taken into consideration and these include inspection of grain at boarders and ship boarding, fumigation and phytosanitary certification (Tyler and Hodges, 2002). Grain drying can also be utilized. Level of dryness for safety corresponds to 30% RH (McFarlane, 1988). Enhanced grain drying and aeration should be advantageous especially in regions where natural aeration may achieve significant nocturnal cooling and maintain the coolest possible conditions (McFarlane, 1988). Airtight storage, removal of sheath before storage and selective segregation of infested cobs can be incorporated in IPM programs. However, it is not possible to recommend with certainty the management tactics of LGB habitat to reduce LGB incidence due to failure to reveal links field and store populations of LGB (Hill *et al.,* 2002).

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Experimental units and management.

The research project consisted of laboratory experiments to evaluate the tolerance of maize varieties used by farmers in Zimbabwe and to evaluate the efficacy of the chemicals used by seed companies to treat their seed and insecticides recommended and used by farmers in Zimbabwe. Chemical bioassays were conducted in the Laboratory. There were a total of four distinct experiments that were conducted. These experiments are:

1. Bioassay on white maize grain variety SC 403 evaluating four commercial insecticides and wood ash.
2. Bioassay on yellow maize grain variety PhB 30D50 evaluating four commercial insecticides and wood ash.
3. Bioassay on treated seed against untreated seed for seed produced by four seed companies.
4. Bioassay on the Manyika white maize flint landrace with treated and untreated components.

The maize varieties used in the experiments were selected from a wide range of varieties used by farmers in Zimbabwe using random selection under the categories, white maize, yellow maize, flint maize and dent maize. The grain was winnowed then deep frozen at $0^{o}C$ for a period of 1 week to eliminate foreign insects and mites or any other living contaminants that could have been in the grain. The grain was weighed and placed into 375mls plastic jars with perforated tops to allow ventilation. Plastic containers were used to allow autoclaving of the containers and their contents in the process of discarding at the end of the experiment to make sure the pest is not released into the environment. The grain in each jar weighed 200g.

3.1.1 Experiment 1

SC403, a short season white maize dent variety was used. There were six treatments and three replications. Each treatment had three recording dates. On each recording date, there were three replications for each treatment from which data was collected. To eliminate the possibility of disturbing *Prostephanus truncatus* feeding process, data was collected once from each date. There were three replications for each treatment and three recording dates from which data would be collected once and the jars discarded. Each treatment had nine jars for the whole experiment and a total of 54 experimental units. After placing 200g maize grain in each container, the chemicals that were used as the treatments were incorporated into the jars using recommended rates on the labels of the chemicals (Table 3.1). The jars were labeled with codes for identity purposes, for example, A1, A2, A3, B1, B2, and B3. The letters represented the chemical used or the treatment and the numbers represented the treatment number. Each jar was also labeled with the date of data collection and recording (Plate 3.1)

	Treatment per 200g maize	Maize Varieties		Inoculation per 200g maize
		White Variety	Yellow Variety	
1	0.1g Superguard Dust Insecticide (Pirimiphos methyl 16g/kg + Permethrin 4g/kg)	SC403	PHB30D50	15 unsexed adult LGB
2	0.1g Chikwapuro Grain Protectant (Pirimiphos methyl 2.5%(m/m) + Deltamethrin)	SC403	PHB30D50	15 unsexed adult LGB
3	0.1g Shumba Super Dust Grain Protectant (Fenitrothion 1% + Deltamethrin 0.13%)	SC403	PHB30D50	15 unsexed adult LGB
4	10g wood ash	SC403	PHB30D50	15 unsexed adult LGB
5	0.1g Actelic Gold Chirindamatura Dust (Pirimiphos methyl 16g/kg + Thiamethoxam)	SC403	PHB30D50	15 unsexed adult LGB
6	Control (no chemical)	SC403	PHB30D50	15 unsexed adult LGB

Table 3. 1: Treatments for experiment 1 and 2: Bioassay on four grain protectants and wood-ash using the white variety SC403 (Seed-Co) and the yellow variety PHB30D50 (Pioneer)

3.1.2 Experiment 2

PHB30G19, a yellow maize, semi flint variety was used. There were six treatments, three replications. Each treatment had three recording dates. On each recording date, there were three replications for each treatment from which data was collected. To eliminate the possibility of disturbing LGB feeding process, data was collected once from each date. There were three replications for each treatment and three recording dates from which data would be collected once and the jars discarded. Each treatment had nine jars for the whole experiment and a total of 54 experimental units. After placing 200g maize grain in each container, the chemicals that were used as the treatments were incorporated into the jars using recommended rates on the labels of the chemicals (Table 3.1). The jars were labeled with codes for identity purposes, for example, A1, A2, A3, B1, B2, and B3. The letters represented the chemical used or the treatment and the numbers represented the treatment number. Each jar was also labeled with the date of data collection and recording (Plate 3.1)

Plate 3. 1: Random placement of labelled jars in experiments 1, 2, 3 and 4.

3.1.3 Experiment 3

There were treated seeds and untreated seeds for four different varieties from four seed companies. The treatments in this experiment were the chemicals used by the seed companies to treat their seed. There was a comparison of treated and untreated seed using the t-test. The treatments for this experiment are shown in Table 3.2. There were three replications for the varieties both treated and untreated and three recording dates from which data was collected once and the jars discarded. The whole experiment had 9×2×4 = 72 experimental units. Properties of the chemicals used by seed companies are given in Table 3.3. No chemicals were added by the researcher in this experiment. The initial weight of the maize in the jars was 200g. Grain weight was recorded after every 28 days over a total period of 84 days.

Table 3. 2: Treatments for experiment 3: Treated vs. untreated seed from four seed companies

	Treatment	Comparison	Inoculation per 200g maize
1	ZM521 + Apron star	ZM521 untreated	15 unsexed adult LGB
2	AC71 + Superguard 50EC	AC71 untreated	15 unsexed adult LGB
3	PHB30G19 + Superguard 50EC	PHB30G19 untreated	15 unsexed adult LGB
4	PAN53 + Superguard 50EC	PAN53 untreated	15 unsexed adult LGB

Table 3. 3: Insecticides used by selected seed companies for their maize varieties

Seed Co.	Variety	Insecticide	Chemical group	Active ingredients
Prime seeds	**ZM521**	Apron star	Neonicotinoid	Thiamethoxam

				Mefenoxam
ARDA seeds	**AC71**	Superguard 50EC	Organophospate	Pirimiphos methyl 0-2diethylamino-6-methyl pyrimidin-4-yl 0,0-dimethyl phosphorothoate C11H20N3O3PS
			Pyrethroid	Permethrin 3-phenoxybenzyl (1RS, 3RS,1RS,3SR) -3-2-(2,2- dichlorovinyl) -2,2-dimethylcyclopropanecarboxylate C21H20Cl2O3
PIONNER	**PHB30G19**	Superguard 50EC	Organophospate	Pirimiphos methyl 0-2diethylamino-6-methyl pyrimidin-4-yl 0,0-dimethyl phosphorothoate C11H20N3O3PS
			Pyrethroid	Permethrin 3-phenoxybenzyl (1RS, 3RS,1RS,3SR) -3-2-(2,2- dichlorovinyl) -2,2-dimethylcyclopropanecarboxylate C21H20Cl2O3
PANNAR	**PAN 53**	Superguard 50EC	Organophospate	Pirimiphos methyl 0-2diethylamino-6-methyl pyrimidin-4-yl 0,0-dimethyl phosphorothoate C11H20N3O3PS
			Pyrethroid	Permethrin 3-phenoxybenzyl (1RS, 3RS,1RS,3SR) -3-2-(2,2- dichlorovinyl) -2,2-dimethylcyclopropanecarboxylate C21H20Cl2O3

3.1.4 Experiment 4

The experiment was a comparison between treated and untreated Manyika, flint white maize landrace. The variety is a landrace commonly grown in Zimbabwe and Mozambique. Actelic Gold Chirindamatura Dust was used to treat the seed using recommended rates on the label of the chemical. The comparison of treated and untreated Manyika variety was done using the t-test as the tool for analysis.

3.2 Variables measured

The variables of concern were grain weight, frass weight, LGB mortality and LGB population. Data that was recorded was on Grain weight; frass weight; LGB population counts and; LGB mortality (%) at 28 days, 56 days and 84 days.

3.2.1 Larger grain borer mortality

The dead insects were recorded after every 28 days on 3 distinct dates for experiments one and two. Percentage mortality was determined. Treatment mortality was corrected using Abbott's (1925) formula of corrected treatment mortality:

$$\text{Corrected treatment mortality} = \frac{(\%\ \text{mortality in treatment} - \%\ \text{mortality in control})}{(100 - \%\ \text{mortality in control})} \times 100$$

3.2.2 Grain and frass weight

The contents of the jars were put through a sieve over a dry metal dish to separate the frass and the grains. Once separated, the frass was brushed off from the dish onto the scale. Weight was taken and recorded. Grain was weighed separately and weight was recorded for all four experiments.

3.2.3 LGB population counts

After sieving the contents of the jars to separate maize kernels and frass, the LGB beetles became visible and easy to count. The populations counted included the initial 15 LGB beetles infested during experiment setting up and those that occurred after the setting up of the experiments. The counts were conducted at 28 days, at 56 days and at 84 days for experiment one and two

3.3 Data collection

Data for all the 4 experiments was collected and recorded for 3 distinct dates. Data collection was done after every 28 days on dates relating to the date each experiment was initially set. For all experiments, data recording started 28 days after set up date and the recording dates for all the experiments were 28 days apart (table 3.4).

Table 3. 4: Initial experiment setup dates and recording dates for the four experiments.

Experiment number	Set up date	Recording date 1	Recording date 2	Recording date 3
1	5/11/2013	1/12/2013	31/12/2013	28/1/2014
2	10/12/2013	7/1/2014	4/2/2014	4/3/2014
3	5/11/2013	1/12/2013	31/12/2013	28/1/2014
4	12/11/2013	10/12/2013	7/1/2014	4/2/2014

3.4 Data analysis

For experiments 1 and 2, data was subjected to ANOVA using MINITAB 13 statistical package where the experimental units were considered to be essentially homogenous. For experiment 3, data analysis based on the t-test for each of the varieties with a comparison between the treated seed and untreated seed. Each variety was analyzed on its own in a bid to compare treated and untreated seed. For experiment 4, t-tests were used as a tool for analysis to come out with results of the comparisons.

CHAPTER 4

4.0 RESULTS

4.1 Grain weight, Frass weight gain, Percent mortality and Post emergence pest progeny for experiment 1 on white maize variety SC403.

4.1.1 Grain weight for experiment one on white maize variety (SC403).

***At 28 days**:* As indicated in table 4.1, there were no significant differences between Superguard Dust Insecticide, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust on grain weight. Wood-ash was significantly different from Superguard Dust Insecticide, Chikwapuro Grain Protectant, Actelic Gold Chirindamatura Dust and Shumba Super Dust Grain Protectant, with a low grain weight compared to the pesticide treatments. Wood ash was significantly different from the control with a low grain weight compared to the control.

***At 56 days**:* As shown in table 4.1, on grain weight, there were no significant differences between Superguard Dust Insecticide, Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant and Shumba Super Dust Grain Protectant. There was no significant difference between wood-ash and the control. There were significant differences between wood-ash and the insecticide protectants (Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Superguard Dust Insecticide) with wood-ash having significantly low grain weight at 56 days.

At 84 days: As indicated in table 4.1, on grain weight, there were no significant differences between Superguard Dust Insecticide, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust. There was no significant difference between wood-ash and the control. There was a significant difference between wood- ash and the insecticide protectants (Actelic Gold Chirindamatura, Chikwapuro Grain Protectant, Superguard Dust Insecticide and Shumba Super Dust Grain Protectant) with wood-ash having a significantly lower grain weight at 84 days.

Table 4. 1: Trend on mean grain weights for chemical/cultural treatments on SC403 at 28 days, 56 days and 84 days.

Chemical(s)/ cultural control	Mean grain weight ± SE at 28 days[1]	Mean grain weight ± SE at 56 days[1]	Mean grain weight ± SE at 84 days[1]
Superguard Dust Insecticide	197.86 ±1.30[a]	191.29±3.73[a]	186.36±5.61[a]
Chikwapuro Grain Protectant	197.98 ±0.81[a]	197.04±0.39[a]	194.82±4.41[a]
Shumba Super Dust Grain Protectant	198.66 ±0.90[a]	198.08±0.64[a]	191.97±3.53[a]
Wood-ash	192.49 ±0.06[c]	164.26±15.78[b]	163.69±3.89[b]
Actelic Gold Chirindamatura Dust ®	199.01±0.51[a]	197.54±0.72[a]	196.21±0.15[a]
Control (no chemical)	194.66±0.71[b]	170.22±8.47[b]	160.22±6.23[b]

[1] means followed by the same letter in a column are not significantly different from each other.

4.1.2 Frass weight for experiment one on white maize variety (SC403).

At 28 days: As indicated in table 4.2, on frass weight there was no significant difference between Superguard Dust Insecticide, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant, and Actelic Gold Chirindamatura Dust. Wood-ash had significantly more frass weight compared to Superguard Dust Insecticide, Chikwapuro Grain Protectant, Actelic Gold Chirindamatura Dust and Shumba Super Dust Grain Protectant. On the other hand Wood-ash and the control were not significantly different from each other.

At 56 days: On Frass weight, there were no significant differences between Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust ($p>0.05$). There was also no significant difference between Superguard Dust Insecticide, Actelic Gold Chirindamatura Dust and Chikwapuro Grain Protectant ($p>0.05$). Shumba Super Dust Grain Protectant, Superguard Dust Insecticide and wood-ash were significantly different ($p<0.05$) from each other with Shumba Super Dust Grain Protectant having the highest grain weight, followed by Superguard dust and wood-ash had the least grain weight at 56 days.

At 84 days*:* As indicated in table 4.2, on frass weight, there were no significant differences between Superguard Dust Insecticide, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust. There was no significant difference between wood-ash and the control. There was a significant difference between wood-ash and the insecticide protectants (Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant, Superguard and Shumba Super Dust Grain Protectant) ($p<0.05$) with wood-ash having a significantly higher frass weight at 84 days.

Table 4. 2: Trend on mean frass weights for chemical/cultural treatments on SC403 at 28 days, 56 days and 84 days.

Chemical(s)/ cultural control	Mean frass weight ± SE at 28 days[1]	Mean frass weight ± SE at 56 days[1]	Mean frass weight ± SE at 84 days[1]
Superguard Dust Insecticide	1.39±0.65[ab]	4.37±1.47[b]	5.72±2.22[a]
Chikwapuro Grain Protectant	1.38±0.79[ab]	2.53±0.45[ab]	3.93±1.05[a]

Shumba Super Dust Grain Protectant	0.78±0.93[ab]	0.99±0.18[a]	2.03±2.68[a]
Wood-ash	3.08±0.42[c]	9.44±0.51[c]	12.48±2.58[b]
Actelic Gold Chirindamatura Dust ®	0.33 ±0.43[a]	2.80±0.89[ab]	2.27±0.3[a]
Control (no chemical)	2.29±0.77[bc]	9.27±1.11[c]	14.42±1.97[b]

[1] means followed by the same letter in a column are not significantly different from each other.

4.1.3 Percent mortality for experiment one on white maize variety (SC403).

At 28 days: On the percentage mortality, as shown in table 4.3, Superguard Dust Insecticide, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust were not significantly different from each other with high mortality rates and lower Post emergence insect progeny at 28 days. There was a significant difference between wood-ash and the insecticide treatments

At 56 days: On LGB mortality, there were no significant differences between Superguard Dust Insecticide, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust. There was a significant difference between wood-ash and the insecticide protectants with wood-ash having the lowest mortality at 56 days as shown in table 4.3.

At 84 days: On LGB percent mortality, there were no significant differences between Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Superguard Dust Insecticide. There were significant differences between wood-ash and the grain protectant chemicals (Chikwapuro Grain Protectant, Actelic Gold Chirindamatura Dust, Shumba Super Dust Grain Protectant and Superguard) with wood-ash having significantly lower percent mortality compared to the four insecticide grain protectants as indicated in table 4.3.

Table 4. 3: Trend on % mortality for treatments on SC403 at 28 days, 56 days and 84 days.

Treatment	**Corrected mortality (%) at 28 days[1]**	**Corrected mortality (%) at 56 days[1]**	**Corrected mortality (%) at 84 days[1]**
Superguard Dust Insecticide	54.79(1.72)[a]	55.65(1.75)[a]	51.24(1.76)[a]
Chikwapuro Grain Protectant	76.98(1.88)[a]	76.03(1.87)[a]	64.54(1.81)[a]
Shumba Super Dust Grain Protectant	60.78(1.78)[a]	61.26(1.78)[a]	61.64(1.78)[a]
Wood-ash	2.22(0.56)[b]	1.74(0.16)[b]	5.68(0.48)[b]
Actelic Gold Chirindamatura Dust ®	82.35(1.91)[a]	87.16(1.94)[a]	77.12(1.89)[a]

[1]means separated using logarithm values in brackets: means followed by the same letter in a column are not significantly different from each other.

4.1.4 LGB populations for experiment one on white maize variety (SC403).

At 28 days: As indicated in table 4.4, there was no significant difference in LGB populations between Chikwapuro Grain Protectant, Superguard Dust Insecticide, Actelic Gold Chirindamatura Dust and Shumba Super Dust Grain Protectant. There were no significant differences between wood-ash, Superguard Dust Insecticide and the control. Significant differences were noted between LGB populations in Chikwapuro (23.33insects), Actelic Gold Chirindamatura Dust (18 insects), Shumba dust (27) and those of Wood-ash (61) and the control (48 insects) with wood-ash having the highest LGB population at 28 days.

At 56 days: There were no significant differences between Superguard Dust Insecticide, Chikwapuro, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust ($p>0.05$). These all had low populations. Wood ash and the control were not significantly different from each other with both having high LGB populations compared to the other treatments. Wood-ash was significantly different from Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Superguard Dust Insecticide ($p<0.05$) with wood-ash having high LGB population of 200insects as shown in table 4.4

At 84 days: As shown in table 4.4, there were no significant differences between Chikwapuro Grain Protectant, Actelic Gold Chirindamatura Dust and Shumba Super Dust Grain Protectant. There was no significant difference between Superguard Dust Insecticide and Shumba Super Dust Grain Protectant. There was a significant difference in LGB populations between Chikwapuro Grain Protectant and Actelic Gold Chirindamatura Dust; Superguard and; wood-ash ($p<0.05$). Wood-ash had a significantly higher LGB population (238 insects) compared to Superguard Dust Insecticide (64 insects) and Actelic Gold Chirindamatura Dust (31 insects) and Chikwapuro Grain Protectant (36 insects).

Table 4. 4: Trend on LGB populations for treatments on SC403 at 28 days, 56 days and 84 days.

Treatment	Mean LGB population at 28 days ± SE[1]	Mean LGB population at 56 days ± SE[1]	Mean LGB population at 84 days ± SE[1]
Superguard Dust Insecticide	31.33 ± 0.58[a]	44 ± 3.61[a]	64 ± 7.94[b]
Chikwapuro Grain Protectant	23.33 ± 3.06[a]	30 ± 1.73[a]	36 ± 8.19[a]
Shumba Super Dust Grain Protectant	27.00 ± 1.00[a]	38 ± 5.57[a]	49 ± 5.57[ab]
Wood-ash	61.00 ± 8.72[b]	200 ± 51.12[b]	238 ± 19.08[c]
Actelic Gold Chirindamatura Dust ®	18.00 ± 2.00[a]	24 ± 2.65[a]	31 ± 3.61[a]
Superguard Dust Insecticide	48.00 ± 14.18[ab]	177 ± 16.70[b]	261 ± 20.66[c]

[1] means followed by the same letter in a column are not significantly different from each other.

4.2 Grain weight, Frass weight gain, Percent mortality and Post emergence pest progeny for experiment 2 on yellow maize variety PHB30D50.

4.2.1Grain weight for experiment one on yellow maize variety (PHB30D50).

At 28 days: There were no significant differences between Superguard Dust Insecticide, Chikwapuro Grain Protectant, Actelic Gold Chirindamatura Dust and Shumba Super Dust Grain Protectant. There was a significant difference between Wood-ash and the four insecticide grain protectants (Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Superguard Dust Insecticide) with wood-ash having a low mean grain weight. There was a significant difference between wood-ash and the control with the control having the least mean grain weight of 190.49g as shown in table 4.5.

At 56 days: As indicated in table 4.5, there was no significant difference between Actelic Gold Chirindamatura Dust, Shumba Super Dust Grain Protectant and Chikwapuro Grain Protectant. Superguard Dust Insecticide and Chikwapuro Grain Protectant were not significantly different from each other. There was a significant difference between Superguard Dust Insecticide and Actelic Gold Chirindamatura Dust and Shumba Super Dust Grain Protectant ($p<0.05$). Wood-ash was significantly different from the other four insecticide grain protectants (Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Superguard Dust Insecticide) with the least mean grain weight of 190.78g and was significantly different from the control which had a mean grain of 193.99g weight.

At 84 days: There were no significant differences between Actelic Gold Chirindamatura Dust, Shumba Super Dust Grain Protectant and Chikwapuro Grain Protectant. Also the difference between Superguard Dust Insecticide, Chikwapuro Grain Protectant and Shumba Super Dust Grain Protectant was not significant. There was no significant difference between wood-ash and the Control. Actelic Gold Chirindamatura Dust, wood-ash and Superguard Dust Insecticide were significantly different from each other with Actelic Gold Chirindamatura Dust having a mean grain weight of 196.65g, Superguard having a mean grain weight of 190.73g and wood-ash having a mean grain weight of 164.56g (table 4.5).

Table 4. 5: Trend on mean grain weights for chemical/cultural treatments on PHB30D50 at 28 days, 56 days and 84 days.

Chemical(s)/ cultural control	Mean grain weight ± SE at 28 days[1]	Mean grain weight ± SE at 56 days[1]	Mean grain weight ± SE at 84 days[1]
Superguard Dust Insecticide	198.13±0.69[a]	194.47±0.73[bc]	187.57±2.30[b]
Chikwapuro Grain Protectant	198.60±0.37[a]	196.39±1.24[ab]	191.83±3.60[ab]
Shumba Super Dust Grain Protectant	198.40±0.48[a]	197.43±0.97[a]	190.73±3.02[ab]
Wood-ash	193.26±1.44[b]	190.78±1.01[d]	164.56±2.63[c]
Actelic Gold Chirindamatura Dust ®	199.00±0.47[a]	198.14±0.78[a]	196.65±0.68[a]
Control (no chemical)	190.49±0.68[c]	193.99±0.66[c]	162.63±4.93[c]

[1] **means followed by the same letter in a column are not significantly different from each other.**

4.2.2 Frass weight for experiment one on yellow maize variety (PHB30D50).

At 28 days: As indicated in table 4.6, Superguard Dust Insecticide, Chikwapuro, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust were not significantly different from each other. There was no significant difference between Superguard Dust Insecticide, Shumba Super Dust Grain Protectant, Actelic Gold Chirindamatura Dust and the control. There was a significant difference between Chikwapuro Grain Protectant and wood-ash and a significant difference between wood-ash and the chemical grain protectants Shumba Super Dust Grain Protectant, Superguard Dust Insecticide and Actelic Gold Chirindamatura Dust was noted.

At 56 days: There was no significant difference between Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Superguard

Dust Insecticide dust at 56 days. There was no significant difference between Chikwapuro Grain Protectant, Superguard dust and the control. There was no significant difference between wood-ash and Superguard Dust Insecticide and the control. Wood-ash with a mean frass weight of 7.05g was significantly different from Shumba Super Dust Grain Protectant (1.74g), Actelic Gold Chirindamatura Dust (1.55g), and Chikwapuro Grain Protectant (2.28g) ($p<0.05$) as shown in table 4.6.

At 84 days: As indicated in table 4.6, there was no significant difference between Actelic Gold Chirindamatura Dust, Shumba Super Dust Grain Protectant dust and Chikwapuro Grain Protectant. Superguard Dust Insecticide and Chikwapuro Grain Protectant were not significantly different from each other. Shumba Super Dust Grain Protectant (2.66g) and Actelic Gold Chirindamatura Dust (2.31g) were significantly different from Superguard dust (5.42g). There were significant differences between wood-ash (14.35g), Superguard Dust Insecticide and Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust.

Table 4. 6: Trend on mean frass weights for chemical/cultural treatments on PHB30D50 at 28 days, 56 days and 84 days.

Chemical(s)/ cultural control	**Mean frass weight ± SE at 28 days[1]**	**Mean frass weight ± SE at 56 days[1]**	**Mean frass weight ± SE at 84 days[1]**
Superguard Dust Insecticide	1.69 ± 0.17^{ab}	4.40 ± 1.64^{abc}	5.42 ± 1.29^{b}
Chikwapuro Grain Protectant	0.46 ± 0.45^{a}	2.28 ± 1.38^{ab}	3.96 ± 0.93^{ab}
Shumba Super Dust Grain Protectant	1.06 ± 0.39^{ab}	1.74 ± 1.56^{a}	2.66 ± 0.87^{a}

Wood-ash	3.60±1.44[c]	7.05±2.32[c]	14.35±0.91[c]
Actelic Gold Chirindamatura Dust ®	0.67±0.28[ab]	1.55±0.40[a]	2.31±0.68[a]
Control (no chemical)	2.13±0.29[bc]	5.49±0.85[bc]	14.24±2.16[c]

[1] means followed by the same letter in a column are not significantly different from each other.

4.2.3 Percent mortality for experiment one on yellow maize variety (PHB30D50).

At 28 days: As indicated in table 4.7, there was no significant difference between Superguard Dust Insecticide, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust. There was a significant difference between wood-ash and the four chemical grain protectants (Superguard Dust Insecticide, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust) with wood-ash having the least LGB percent mortality of 2.05%

At 56 days: there was no significant difference between Superguard Dust Insecticide, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust. There was a significant difference between wood-ash and the four chemical grain protectants (Superguard, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust) with wood-ash having the least LGB percent mortality of 2.18% as shown in table 4.7.

At 84 days: As indicated in table 4.7, there was no significant difference between Actelic Gold Chirindamatura Dust, Shumba Super Dust Grain Protectant and Chikwapuro Grain

Protectant. Superguard Dust Insecticide, Chikwapuro Grain Protectant and Shumba Super Dust Grain Protectant were not significantly different from each other. There were significant differences between wood-ash (7.07%), Actelic Gold Chirindamatura Dust (76.21%) and Superguard Dust Insecticide (39.67%) with wood-ash having the least percent mortality among all treatments.

Table 4. 7: Trend on % mortality for treatments on PHB30D50 at 28 days, 56 days and 84 days.

Treatment	Corrected mortality (%)[1] at 28 days	Corrected mortality (%)[1] at 56 days	Corrected mortality (%)[1] at 84 days
Superguard Dust Insecticide	61.99(1.79)[a]	60.09(1.78)[a]	39.67(1.60)[b]
Chikwapuro Grain Protectant	72.08(1.86)[a]	71.22(1.86)[a]	61.09(1.78)[ab]
Shumba Super Dust Grain Protectant	68.73(1.83)[a]	62.54(1.80)[a]	44.24(1.64)[ab]
Wood-ash	2.05(0.85)[b]	2.18(0.34)[b]	7.07(0.83)[c]
Actelic Gold Chirindamatura Dust ®	80.42(1.90)[a]	82.09(1.91)[a]	76.21(0.88)[a]

[1]means separated using logarithm values in brackets: means followed by the same letter in a column are not significantly different from each other.

4.2.4 LGB populations for experiment one on yellow maize variety (PHB30G19)

At 28 days: As shown in table 4.8, there was no significant difference between Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust ($p>0.05$). Superguard Dust Insecticide, Shumba Super Dust Grain Protectant and Chikwapuro Grain Protectant were not significantly different from each other ($p>0.05$). Significant differences in LGB populations existed between Actelic Gold

Chirindamatura Dust, Superguard Dust Insecticide and wood-ash ($p<0.05$) with wood-ash having the highest population of 70 insects, followed by Superguard Dust Insecticide (34 insects) and Actelic Gold Chirindamatura Dust (22 insects) at 28 days as shown in table 4.8.

At 56 days: As indicated in table 4.8, there was no significant difference between Chikwapuro Grain Protectant, Actelic Gold Chirindamatura Dust and Shumba Super Dust Grain Protectant ($p>0.05$) in the LGB populations in maize treated with the chemicals. There was no significant difference between Superguard Dust Insecticide, Chikwapuro Grain Protectant and Shumba ($p>0.05$). LGB populations that were found in maize treated with Actelic Gold Chirindamatura Dust, Superguard Dust Insecticide and wood-ash were significantly different from each other with wood-ash (184 insects) having the highest LGB populations followed by Superguard Dust Insecticide (50 insects) and Actelic Gold Chirindamatura Dust (30 insects) as shown in table 4.8

At 84 days: As indicated in table 4.8, the LGB populations found in maize treated with Actelic Gold Chirindamatura Dust and Chikwapuro Grain Protectant were not significantly different from each other. There was no significant difference between Superguard dust and Shumba Super Dust Grain Protectant ($p>0.05$). The populations in maize treated with Actelic Gold Chirindamatura Dust (38 insects) and Chikwapuro Grain Protectant (42 insects) were significantly lower than the populations in maize (68 insects) treated with Superguard Dust Insecticide and Shumba Super Dust Grain Protectant (53 insects) at 84 days ($p<0.05$). Wood-ash (223 insects) had a significantly higher LGB population compared to Superguard, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Actelic Gold Chirindamatura Dust.

Table 4. 8: Trend on LGB populations for treatments on PHB30D50 at 28 days, 56 days and 84 days.

Treatment	Mean LGB populations at 28 days[1]	Mean LGB populations at 56 days[1]	Mean LGB populations at 84 days[1]
Superguard Dust Insecticide	34 ± 2.00[b]	50.00 ± 3.61[b]	68.00 ± 1.73[c]
Chikwapuro Grain Protectant	27.00±3.46[ab]	36.00 ± 2.00[ab]	42.00 ± 2.00[ab]
Shumba Super Dust Grain Protectant	31.00±2.65[ab]	42.00 ± 2.65[ab]	53.00 ± 3.61b[c]
Wood-ash	70.00 ± 10.58[c]	184.00 ± 11.14[c]	223.00 ± 8.19[d]
Actelic Gold Chirindamatura Dust ®	22.00±1.73[a]	30.00 ± 2.65[a]	38.00 ± 2.65[a]
Control (no chemical)	56.00±4.00[d]	175.00 ± 7.94[c]	234.00 ± 7.55[d]

[1] means followed by the same letter in a column are not significantly different from each other.

4.3 Experiment 3: Bioassay on treated and untreated seed maize from different seed companies: ZM521 (Prime seeds), AC71 (ARDA seeds), PHB30G19 (Pioneer) and PAN 53 (Pannar).

ZM521

As indicated in table 4.9, at 28 days, there was a significant difference between treated ZM521 and untreated ZM521 on grain weight loss. At 54 days, there was a significant difference between treated ZM521 and untreated ZM521. At 86 days, there was significant difference between treated and untreated ZM521.

AC71

There was no significant difference between treated and untreated AC71at 28 days on grain weight loss. At 56 days, there was no significant difference between treated AC71 and untreated AC71 on grain weight loss. However, as shown in table 4.9, at 84 days there was a significant difference between treated AC71 (159g) and untreated AC71 (153.4g).

PHB30G19

As pointed out in table 4.9, at 28 days, there was a significant difference between treated PHB30G19 and untreated PHB30G19. At 56 days, there was significant difference between treated and untreated PHB30G19 and at 84 days there was significant difference between treated and untreated PHB30G19. Henceforth, there was significant difference between treated and untreated PGH30G19 at all three dates.

PAN 53

There was no significant difference between treated and untreated PAN53 at 28 days. At 56 days, there was no significant difference between treated PAN53 and untreated PAN53. At 84 days, there was no significant difference between treated and untreated PAN53. Henceforth, there was no significant difference between treated and untreated PAN53 on grain weight loss at all dates.

Table 4. 9: Trend on grain weight loss for ZM521, AC71, PHB30G19 and PAN 53 at 28 days, 56 days and 84 days.

Variety		Mean ± SE[1] at 28 days	Mean ± SE[1] at 56 days	Mean ± SE[1] at 84 days
ZM521	**T**[2]	197.6±0.93[a]	193.4±2.17[a]	186.3±1.37[a]

	UT	175.9±11.13[b]	166.7±1.85[b]	154.1±5.35[b]
AC71	**T**	168.9±2.31[a]	165.2±3.46[a]	159±1.61[a]
	UT	166.6±2.20[a]	163.5±1.85[a]	153.4±1.85[b]
PHB30G19	**T**	195.5±0.80[a]	173.1±2.56[a]	173.8±1.39[a]
	UT	171.2±1.13[b]	167.7±2.31[b]	167.7±1.03[b]
PAN53	**T**	176.3±18.71[a]	171.2±1.23[a]	159.5±2.90[a]
	UT	173.5±4.93[a]	168.9±7.78[a]	156±1.82[a]

[1] means followed by the same letter in a column for each variety are not significantly different from each other. [2]T = treated, UT = untreated.

4.4 Experiment 4: Bioassay on treated and untreated Manyika Landrace (Hickory king).

As indicated in table 4.10, there is a significant difference between treated Manyika landrace (199.1g) and untreated Manyika landrace (177.3). At 56 days, there is a significant difference between treated Manyika (197.5g) and untreated Manyika (171.6g) landrace At 84 days, there is a significant difference between treated and untreated Manyika landrace with an evident change in weight loss from the previous dates (table 4.10).

Table 4. 10: **Trend on grain weight loss for Manyika landrace at 28 days, 56 days and 84 days.**

		Mean ± SE[1] at 28 days	Mean ± SE[1] at 56 days	Mean ± SE[1] at 84 days
Manyika Landrace	**T[2]**	199.1±0.56[a]	197.5±0.53[a]	196.7±0.17[a]
	UT	177.3±18.15[b]	171.6±0.40[b]	154.7±5.86[b]

[1] means followed by the same letter in a column for each variety are not significantly different from each other. [2]T =treated, UT = untreated.

CHAPTER 5

5.0 DISCUSSION

5.1 Efficacy of insecticide grain protectants and the use of wood-ash to control and manage *Prostephanus truncatus* in stored maize.

The dust formulation pesticides used in Experiment 1 and 2 are all registered as grain protectants for larger grain borer control and they are used by farmers in Zimbabwe. The chemical grain protectants in the research were all found to be effective with Actelic Gold

Chirindamatura Dust, Chikwapuro Grain Protectant, Shumba Super Dust Gain Protectant and Superguard Dust Insecticide exhibiting high levels of effectiveness. This renders the combinations of active ingredients in the chemical grain protectants to be effective as they have the capacity to manage and control LGB. All the active ingredients in the insecticides act on the nervous system of the insect pests but they act on different components of the nervous system with different modes of action. Pirimiphos methyl, an organophosphate found in Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant and Superguard Dust Insecticide, and fenitrothion found in the chemical composition of Shumba dust act as inhibitors of acetylcholinesterase enzyme (Fukuto, 1990; Ofosu, 1977). Pyrethroids found in the chemical compositions of Shumba Super Dust Gain Protectant, Chikwapuro Grain Protectant and Superguard Dust Insecticide act on the axonal membrane causing permanent depolarization of the axonal membrane (Narashi, 1971; Thatheyus and Selvam, 2013). Actelic Gold Chirindamatura Dust has a neonicotinoid (thiamethoxam) that mimics the neurotransmitter acetylcholine causing over stimulation (Arthur *et al.,* 2004). These differences in mode of actions of active ingredients found in the chemical pesticides reduce the possibility of a development of resistance of the pest against the action of the insecticides. Thiamethoxam is a new generation neonicotinoid which is toxic to stored product pests including LGB. Because of its unique mode of action and tolerance to environmental factors; it can be rendered effective even in long storage periods (Authur *et al.,* 2004). This is one of the reasons why Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and Superguard Dust Insecticide exhibited high levels of effectiveness against LGB. The degree of survival of an insect pest is dependent upon the concentration of the insecticide. For instance, thamethoxam applied at 1 - 4 ppm can give 90-100% control depending on the period of exposure of the insect to the chemical (Authur *et al*., 2004). The application of the insecticides that were used at the recommended rates as on the labels also contributed to the effectiveness of the chemicals. The recommended rates are sufficient enough to manage and control LGB.

The degree of survival of an insect pest is also dependent upon the characteristics of an insecticide (Authur *et al*., 2004). Although toxic and effective against LGB, Neonicotinoids, pyrethroids and organophosphates have different periods of residual activity. Pyrethroids are toxic and are applied at low rates, but they are not photo-stable as they degrade in sunlight while organophosphates have short-lived residual activity (Thatheyus and Selvam, 2013). No evidence of these differences could be attributed to the chemicals as they were all significantly effective. Nevertheless, interaction between concentration of the chemical, exposure and characteristics of the chemical is important in controlling larger grain borer (Authur *et al*., 2004). On the other hand, with neonicotinoids, there are no cases of cross resistance to the carbamate, organophosphate or synthetic pyrethroids which makes neonicotinoids more effective and important pest management insecticides (Hara, 2009) and additionally, they are environmentally friendly as they are close mimics of insect (Ach) than for mammals (Brown and Ingianni, 2013; Hara, 2009). This means that although not significantly different from each other, to some extent, Actelic Gold Chirindamatura Dust, Chikwapuro, Superguard Dust Insecticide and Shumba will have different residual periods. With time; they lose their effectiveness and consequently, LGB is less susceptible to insecticides (Authur *et al*., 2004). This explains the increase emergence of new insect progeny in time as evident at 28 days, 56days and at

84 days for both PHB30G19 and SC403. Chances of LGB survival in chemical applied grain are increased by their ability to reproduce at high rates compared to other storage pests (Makundi *et al* 2010).

The cultural method of using wood-ash seems ineffective and has no effect on managing and/or controlling LGB. The abrasion effect of the wood ash, expected to work on the LGB by way of injuring the insect so that the insect later dies of desiccation, is not effective on LGB beetles. This could be due to the hard and protective exoskeleton of the LGB. The coleopteran features and structure protect the insects from external forces that might injure the insects with its head and thorax having a firm exoskeleton. The abdomen and hind wings are protected by the hard fore wings. The strong exterior structure of the LGB protects it from external forces such as the abrasion effect of the wood-ash. Larvae of LGB could however be affected by the abrasion effect because of their softness although this was not evident considering the increasing LGB populations at 28 days, at 56 days and at 84days for both SC403 and PHB30G19.

5.2 Treated and Untreated seed maize: ZM521, AC71, PHB30G19 and PAN 53.

Apron star 45 WS was used to treat ZM521 and was evidently effective in treating LGB. This could be because of the active ingredient, thiamethoxam (neonicotinoid) which is highly effective against LGB (Authur *et al.,* 2004). The presence of the Neonicotinoid resulted in the maize samples withstanding the LGB attack as seen also in the samples treated with Actelic Gold Chirindamatura Dust in experiments 1 and 2 hence neonicotinoids have adverse effect on LGB activity and proliferation and are sufficient enough to slow down LGB. Thiamethoxam is therefore an effective protectant of seed maize and the actual level of control would be dependent on the interaction of biological and physical factors such as target insect species, application rate and time interval in which insects were exposed to the insecticide (Authur *et al.,* 2004). It is therefore important to note that *P. truncatus* can be more difficult to kill than other primary or secondary pests. Nevertheless, from the results, we note that *P. truncatus* is susceptible to recommended levels of thiamethoxam in Apron star.

Superguard 50EC is an LGB specific insecticide which was evidently effective on against LGB on PHB30G19. Its chemical composition includes pirimiphos methyl (organophosphate) and permethrin (pyrethroid). However, on PAN53 AND AC71, there was no effective control of LGB despite the maize being treated by Superguard 50EC, a similar chemical used to dress PHB30G19. Considering that the chemical used was Superguard 50EC which was LGB specific, the ineffectiveness could have been a result of chemical degradation due to poor storage or due to earlier dates of application before the selling season of the seed maize.

The observed loss in weight in ZM521, PHB30G19, AC71 and PAN 53 at all dates from the initial 200g could have been because of the existing disadvantages of the nature of the chemicals where pyrethroids are not photo-stable and organophosphates have a shorter residual life (Brown and Ingianni, 2013).

5.3 Varietal tolerance: relationship between variety and extent of damage.

Host-plant resistance is environmentally safe, economically feasible and socially acceptable as a tactic of IPM (Kumar, 2002), but rather difficult with LGB since it has no preference and consumes grain, wood and substances containing cellulose at devastating rates (Rugumamu, 2006). However, LGB attack on Manyika landrace differs from the way it attacks varieties such as ZM521, AC71, PAN 53 and PHB30G19 which therefore supports the fact that maize resistance against LGB exists (Kumar, 2002). The presence of resistance genotypes against LGB attack is attributed to factors such as grain hardness among many (Mwololo *et al.,* 2012). Manyika landrace has flint kernels which reduce LGB activity due to the high energy cost required for LGB to tunnel into the kernels through the hard seed coat of the Manyika variety (Li, 1988). Despite the structure of the mandibles which are described as 'biting-crushing' (Rugumamu, 2006), the Manyika landrace seems to withstand LGB attack because of the hard seed coat and it is not easily disintegrated into powder (Kumar, 2002). However, with time the insect pest eventually penetrates and damages the kernels through tunnelling. Damage is evident at 28, 56 and 84 days although grain weight loss is less than that of ZM521, AC71, PAN 53 and PHB30G19 in both the treated and untreated samples. A combination of the Manyika flint landrace and Chirindamatura is a cocktail for LGB control that ensures effective management and control against the insect. The use of a resistant variety in conjunction with an effective insecticide provides a long term system that maintains insect population in maize at acceptably low levels (Gudrups *et al.,* 2001). White and yellow maize are more or less the same in terms of their chemical composition (Bull, 1928) and if there are any differences, the differences are insignificant (Groenewald and Boyazogla, 1980); and this explains why there are insignificant differences on attack by LGB between the two varieties.

CHAPTER 6

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

Prostephanus truncatus is an important storage pest which causes devastating losses in terms of quantity and quality on stored maize. When no insecticide is applied, there is more grain weight loss than when a chemical insecticide like Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant, Superguard Dust Insecticide, Shumba Super Dust Grain Protectant, Superguard 50EC or Apron star WS 45 is applied. The use of flint varieties such as Manyika landrace (Hickory king) can also help manage LGB to some extent. Farmers should learn to move from the cultural methods they were traditionally used to, such as applying wood-ash as an abrasive, as this proves to be ineffective and rather promotes LGB proliferation. Seed companies should also adopt the use of chemicals that have longer residual periods so as to protect their grain throughout the growing season and ensure that they do not give farmers infested seed. The presence of the pest in Zimbabwe poses a grave danger on the country's maize stock. There is therefore a need to adopt consistent LGB management and control measures through the use of chemicals such as Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant, Superguard Dust Insecticide, Shumba Super Dust Grain Protectant, Superguard 50EC and Apron star WS 45.

6.2 Recommendations

Smallholder farmers and Commercial farmers

Small holder farmers and commercial farmers should use recommended grain protectants such as Actelic Gold Chirindamatura Dust, Superguard Dust Insecticide, Chikwapuro Grain Protectant and Shumba Super Dust Grain Protectant and apply them at recommended rates.

Seed companies

Seed companies should adopt the use of grain protectants, such as Apron star WS 45, Actelic Gold Chirindamatura Dust, Chikwapuro Grain Protectant, Shumba Super Dust Grain Protectant and

Superguard Dust Insecticides that have prolonged residual periods. The chemicals should be applied on perfect timings that allow the seed to remain protected throughout the planting season.

The government of Zimbabwe-Ministry of Agriculture

Farmers should be made aware of the existence of LGB, the dangers the pest poses towards maize production and methods that are effective in managing and controlling the pest.

The government should assist the smallholder farmers in controlling and managing the pest where the farmer has no means to manage or control the pest so as to reduce spread of the LGB.

Importation of maize should be carefully controlled and managed with quarantine measures at all boarders.

REFERENCES

Abate, T., van Huis, A., and Ampofo, J.K.O. 2000. Pest management strategies in traditional agriculture: An African perspective. *Ann. Rev. of Entomol*., **45**: 631-659.

Akob, C.A. and Ewete, F.K. 2010. Effect of four mid-altitude, maize varieties on oviposition, development and sex ratios of *Sitophilus zeamais* (Motschulsky) (Coleoptera: Curculionidae). *African Entomology,* **18**: 253-258.

Anon. 2008. Department for International Development (DFID), Zimbabwe, April 2008 bulletin.

Arthur, F.A., Yue, B. and Wilde, G.E. 2004. Susceptibility of stored-product beetles on wheat and maize treated with thiamethoxam: effects of concentration, exposure interval and temperature. *Journal of Stored Products Research,* **40**: 527-546.

Bajwa, W. I. and M. Kogan. 2002. Compendium of IPM Definitions (CID)- What is IPM and how is it defined in the Worldwide Literature? IPPC Publication No. 998, Integrated Plant Protection Center (IPPC), Oregon State University, Corvallis, OR 97331, USA.

Barbosa, A., Golob, P., and Jenkins, N. 1994. Silica aerogels as alternative protectants of maize against *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) infestations. Proceedings of the 6th International Working Conference on Stored-product Protection.

Bell, R.J., and Waters, F.L. 1982. Environmental factors influencing the development and rate of increase of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) on stored maize. *Journal of Stored Products Research,* **18**: 131-142.

Borgemeister, C., Schneider, H., Adda, C., Affognon, H., Agonnke, D., Biliwa, A., Tchabi, A., Camara, M., Markham, R.H. and Scholz, D. 2010. Biological control of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in Benin and Togo. *International Journal of Biology and Chemical Sciences,* **4(6)** 2397-2408.

Birkinshaw, L.A. and Hodges, J. R. 2000. Improving IPM approaches for LGB control in Africa. *PhAction News*, 3, http://www.iita.org.

Bull, S. 1928. The Principles of feeding farm animals. New York. pp 475.

Brown, A.E., and Ingianni, E. 2013. Mode of Actionof Insecticides and Related Pest Control Chemicals for Production Agriculture, Ornamental and Turf. College of

Computer, Mathematical and Natural Sciences. College of Agriculture and Natural Resources. Department of Entomology: 43 pp13.

CABI. 2010. *Prostephanus truncatus* (Larger Grain Borer) datasheet. Crop Protection Compendium, 2010 Edition. CAB International Publishing. Wallingford, UK. www.cabi.org/cpc. Accessed on 28 Jan 2014.

Derera, J., Giga, P.D. and Pixley, K.V. 2001. Resistance of maize to the maize weevil: II. Non-preference. *African Crop Science Journal,* **9:** 441-450.

Dunstan, W.R and Magazini, I.A. 1981. Outbreaks and new records, Tanzania. The Larger Grain Borer in Stored Products. *FAO Plant Protection Bulletin,* **29**, *80-81.*

Ehler, L.E. 2006. Perspectives Integrated Pest Management (IPM): Definition, Historical Development and Implementation, IPM Department of Entomology, University of California. Pest Management Sciences **DOI : 10.1002.**

FAOSTAT. 2014. World maize (Corn) Production in metric tonnes. GeoHive 2000-2014. Retrived from www.geohive.com/charts/ag_maize.aspx. 10 March 2014.

Fukuto, T.R. 1990. Mechanism of Action of Organophorous and Carbamate Insecticides. *Environmental and Health Perspectives*, **87:** 245-254.

GASGA. 1998. Group for assistance on systems relating to Grains after harvest (3rd edn). Technical Center for Agricultural Rural Co-operation. ACP-EU. Technical leaflet No.1 Larger Grain Borer. June 1998.

Giles, P.H., and Kibata, G.N. (1992). Recent developments in Kenya on the ecology and control of *Prostephanus truncatus.* In: *Implementation of and Further Research on*

Ecology and Control of the Larger Grain Borer. Proceedings of the FAO/GTZ coordination meeting. Lome, Togo. pp 14-16

Giles, P.H, Hill M.G, Nan'ayo, F.L.O, Farrell, G., Strabrawa, A and Wekesa P.W. 1995. Entomological and socio-economic investigations for the development of integrated pest management strategies against *Prostephanus truncatus*. Natural Resource Institute, Chatham, U.K. 273pp.

Golob, P., Broadhead, P., Wright, M. 1990. Susceptibility of *Teretriosoma nigrescens* Lewis. (Coleoptera: Histeridae) to insecticides. In: Hodges R.J, Recent advances in the biology and control of *Prostephanus truncatus* Horn. (Coleoptera: Bostrichidae). Proceedings of the 6th International working conference on stored product protection, **2:** 929-934.

Golob, P., Changjaroen, P., Ahmed, A., and Cox, J. 1985. Susceptibility of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) to insecticides. *Journal of Stored Products Research,* **21(3):** 141-150.

Golob, P. 1988. Current status of the larger grain borer Prostephanus truncatus (Horn) in Africa. *Insect Science and its Application*, **9(6)**, 737-745.

Groenwald, J.W., and Boyazoglu, P.A. 1980. Animal Nutrition concepts and applications. FAO.org.

Gudrups, I ., Floyd, S., Kling, J.G., Bosque-Perez, N.A. and Orchard, J.E. 2001. A comparison of two methods of assessment of maize varietal resistance to the maize weevil, *Sitophilus zeamais* Mitschulsky, and the influence of kernel hardness and size on susceptibility. *Journal of Stored Products Research,* **37:** 287-302.

Haines, C.P. 1991. Insects and arachnids of tropical stored products: their biology and identification – A training manual. Natural Resources Institute (NRI).

Hara, A.H. 2009. Understanding Neonicotionoid Insecticides. CPS Seminar. University of Hawaai at Manoa College of Tropical Agriculture and human resources. May 14 2009.

Hill, M.G., Borgemeister, C. and Nansen, C. 2002. Ecological studies on the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and their implications for integrated pest management. *Integrated Pest Management Reviews,* **7:** 201-221.

Hodges, R.J. 1994. Recent advances in the biology and control of *Prostephanus truncatus* (Coleoptera: Bostrichidae). Proceedings of the 6th international working conference on stored product protection 2: 929-934.

Hodges, R.J. 1982. A review of the biology and Control of the Greater Grain Borer *Prostephanus truncatus* (Horn). *Tropical Stored Prod*. *Inform.*, **43**: 3-9.

Hodges, R.J. 1986. The biology and control of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) – a destructive storage pest with an increasing range. *Journal of Stored Products Research,* **22 (1)**: 1-14.

Hodges, R.J., Dunstan, W.R., Magazini, T., and Golob, P. 1983. An Outbreak of *Prostephanus truncatus* (Horn)(Coleoptera: Bostrichidae) in East Africa. *Protection Ecology*, 5: 183-194

Horn, G.H. 1878 Revision of the Bostrichidae of the United States. *Proc. Am. Phil. Soc.,* **17**, 540-550.

Jean-Pieere, A., Elizabeth, T., Leonce, F., Alassane, G.B. 2013. Preventive, curative and persistent activities of *Lantana camara* and *Psidium guajava* essential oils against *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *International Journal for applied Chemistry,* **9(1):** 1-13.

Kasambala, T., and Chinwada, P. 2011. Modeling the occurrence of *Prostephanus truncatus* (Coleoptera: Bostrichidae) in Southern Malawi. *Journal of stored Products and Postharvest Research,* **2(4)**: 72-78.

Krall, S. 1984. A new threat to the maize farm-level storage in West Africa: *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *Tropical Stored Products Information,* **50**: 26-31.

Kumar, H. 2002. Resistance in maize to the Larger Grain Borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *Journal of Stored Products Research,* **38:** 267-280.

Lankatos, F., and Thuroczy, C. 2002. Parasitoids of xylophagus and phloeophagous insects of the Hungarian coniferous tree species. In: Melika, G. and Thuroczy, C. (eds.). Parasitic wasps: Evolution, Systematics, Biodiversity and Biological Control. Hungary. pp. 341-345.

Li, L. 1988. Behavioral ecology and life history evolution in the Larger Grain Borer, *Prostephanus truncatus* (Horn). PhD Thesis, University of Reading, UK, pp:229.

Makundi, R.H., Swila, N.N., Misangu, R.N.,Rueben, S.W.M., Mwatawala, M., Sikira, A., Kilonzo, B.S., Lyimo, H., Massawe, A.W. and Ishengoma, C. 2010. Dynamics of infestation and losses of stored maize due to the larger grain borer (*Prostephanus* *truncatus* Horn) and maize weevils (*Sitophilus zeamais* Motschulsky). *Archives of Phytopathology and Plant Protection,* **43:** 1346-1355.

Markham, R.H., Wright, V.F., and Rios Ibawa., R.M. 1991. A selective review of research on *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in Kenya. *African Crop Science Journal,* **1:**39-47.

Magellan. 1999. A new pocket GPS 315. Thales Navigation, Inc.

McFarlane, J.A. 1988. Pest management strategies for *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) as a pest of stored maize grain: present status and prospects. *Tropical Pest Management,* **34:** 121-132.

Muhihu, S.K., and Kibata, G.N. 1985. Developing a control program to combat an outbreak of *Prostephanus truncatus* Horn (Coleoptera: Bostrichidae) in Kenya. *Tropical Science*, **25**: 239-248.

Mwololo, J.K., Mugo, S.N., Tefera, T., Okori, P., Munyiri, S.W., Semagn, K., Otim, M. and Beyene, Y. 2012. Resistance of tropical maize genotypes to the larger grain borer. *Journal of Pesticide Science,* **85:** 267-275.

Narashi, T. 1971. Mode of action of pyrethroids. Bull World Health Organs (44).

Nyagwaya, L.D.M., Mvumi, B.M and Saunyama, I.G.M. 2010. The occurrence, distribution and management of the larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) in Zimbabwe. *International Journal of Tropical Insect Science,* **30(4)**: 221-259.

Ofosu, A. 1977. Persistance of Fenitrothion and Pirimiphos-methyl on shelled maize. Food storage section, Crop Research Institute, Private Mail Bag, Ghana. pp4.

OGTR. 2008. The biology of *Zea mays* L. ssp mays (maize or corn). Australian Government, Department of Health and Ageing, Office of the Gene Technology Regular. Version 1: September 2008. pp81.

Omondi, B.V., Jiang, N., Berg, J., and Schulthess, F. 2011. The Flight Activity of *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae) and *Teretrius nigrescens* Lewis. (Coleoptera: Histeridae) in Kenya. *Journal of Stored Products Research,* **47(1):** 13-19.

Pike, V. 1993. Report on the behaviour of *Prostephanus truncatus* in relation to pheromone-baited crevice traps and flight mill performance in Mexico; August–December 1991, Semi-Annual Report R 1914(R). Natural Resources Institute, Chatham Maritime, UK.

Rugumamu, C.P. 2005. Management of insect pest infestations on farm stored maize, Zea mays in Tanzania: A contribution to integrated pest management. Sida/SAREC Research Report, University of Dar Salaam.

Rugumamu, C.P. 2006. Varietal Role in the Management of Larger Grain Borer *Prostephanus truncatus* (Horn) in stored maize. Department of Zoology and wildlife. Conservation, University of Dar es Salaam, Tanz. J. Vol. 32(2) 2006.

Rwegwasira, M.G., Jowah, P. and Mvumi, B.M. 2003. Potential invasion areas by the larger grain borer in Zimbabwe. African Crop Science Conference Proceedings. Vol 6: 254-259.

Sallam, M.N. 2008. Insect damage: Damage on post-harvest. International Center of Insect Physiology and Ecology (ICIPE). pp 38.

Seidu, J.M., Mensah, G.W.K., Zah, V.K., Dankwah, S.S.A., Kwenin, W.K.J., and Mahama, A.A. 2010. The use of solar dryers to control insect infestation in stored grains in Ghana. University of Education-Winneba, College of Agriculture Education. Department of Agriculture Mech. And Engineering. December 2010. *Int. Biol. Chem. Sci.,* **4(6)**: 2397-2408.

Stathers, T. 2003. Combinations to enhance the efficacy of diatomaceous earths against the larger grain borer (Prostephanus truncatus). Proceedings of the Eighth International Working Conference on Stored-product Protection, York, UK, 22– 26 July, 2002. CAB International, Wallingford, UK, pp. 925–929.

Tefera, T., Mugo, S., and Lihkayo, P. 2010. Effects of Insect population density and storage time on grain damage and weight loss in maize due to maize weevil *Sitophilous zeamays* and the larger grain borer *Prostephanus truncatus. Journal of Agricultural Research*, **6(10)**: 2249-2254.

Thatheyus, A.J., and Selvam, A.D.G. 2013. Synthetic pyrethroids: Toxicity and Biodegradation. Post Graduate and Research Department of Zoology. Post Graduate Department of Microbiology. The American College, Madurai. pp4.

Throne, J.E and Eubanks, M.W. 2002. Resistance of tripsacorn to *Sitophilus zeamais* and *Oryzaephilus surinamensis*. *Journal of Stored Products Research,* **38:** 239-245.

Tyler, P.S. and Hodges, R.J. 2002. Phytosanitary measures against Larger Grain Borer, *Prostephanus truncatus*(Horn) (Coleoptera: Bostrichidae) in international trade. *Integrated Pest Management Reviews,* **7:** 279-289.

Wastayn, M. 2013. By products from Corn Starch Proceedings. 64^{th} starch convention in Detmold, Germany, 23/4/2013.

APPENDICES

Appendix 1: Meteorological data on maximum and minimum temperatures and relative humidity for January-December 2012 for Harare, Mutoko, Karoi, Mt Darwin and Chinhoyi Met. Centers

	Harare Belvedere			Mutoko			Karoi			Mt. Darwin			Chinhoyi		
Month	Tmax	Tmin	RH	Tmax	Tmin	RH	Tmax	Tmin	RH	Tmax	Tmin	RH	Tmax	Tmin	RH
January	27.1	16.2	74	27.9	17.2	62	26.8	17.2	77	29.4	18.4	81	25.6	5.8	77
February	27.5	16.6	90	28.6	17.4	52	22.2	17	84	27.4	17.5	89	28.9	17.7	78
March	26.9	15.5	77	28	16.2	51	26.2	16.2	82	27.8	14.5	79	29.2	16.4	70
April	24.7	11.9	71	25.5	12.2	59	25.5	12	84	27.5	10.3	69	28	13.5	66
May	24.1	9.7	65	25.4	10.4	66	25.7	10.1	82	26	7.3	67	26.3	9.5	59
June	22.8	7.6	62	23.4	9.3	79	23.5	7.8	75	24.4	6.8	62	24.2	6.2	55
July	21.9	6.7	60	23	7.5	75	23.9	7	68	24.4	8.9	56	25.6	5.8	52
August	24.4	8.9	52	26	11.5	70	26.5	10.3	66	25.7	13.2	49	26.6	8	44
September	28.9	14.1	35	28.8	14.7	68	29.9	14.4	62	30.2	17	48	30.2	12.1	37
October	29.9	15	52	30.3	17	67	31.3	15.5	55	31.6	17.6	59	31.3	15.5	43
November	29.1	16.1	56	30	17.2	63	30.5	16.4	55	29.4	18.6	73	31.7	18.2	55
December	26.7	16.9	79	27.7	17.1	66	27.2	17.4	79	28.6	18.8	81	28.2	18.4	73

Appendix 2: Data analysis for Grain weight loss: Experiment 1 MINITAB 13 ONE-WAY ANOVA

2. 3: Variate: Grain weights for Experiment 1, Date 1

```
Analysis of Variance for C2
Source     DF        SS        MS        F        P
C1          5   102.034    20.407    31.10    0.000
Error      12     7.874     0.656
Total      17   109.908
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -----+---------+---------+---------+-
1           3   197.863     1.301                       (---*----)
2           3   197.983     0.814                        (---*---)
3           3   198.663     0.900                           (---*---)
4           3   192.493     0.061   (---*---)
5           3   199.010     0.512                            (---*---)
6           3   194.660     0.710           (---*---)
                                   -----+---------+---------+---------+-
Pooled StDev =    0.810             192.5     195.0     197.5     200.0

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                 1           2           3           4           5

       2     -2.3415
              2.1015

       3     -3.0215     -2.9015
              1.4215      1.5415

       4      3.1485      3.2685      3.9485
              7.5915      7.7115      8.3915

       5     -3.3682     -3.2482     -2.5682     -8.7382
              1.0748      1.1948      1.8748     -4.2952

       6      0.9818      1.1018      1.7818     -4.3882      2.1285
              5.4248      5.5448      6.2248      0.0548      6.5715
```

2. 3 :Variate: Grain weights for Experiment 1, Date 2

```
Analysis of Variance for C3
Source     DF        SS        MS        F        P
C1          5    3450.0     690.0    12.33    0.000
Error      12     671.7      56.0
Total      17    4121.7
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -------+---------+---------+---------
1           3    191.29      3.73                   (------*-----)
2           3    197.04      0.39                       (-----*------)
3           3    198.08      0.64                        (-----*-----)
4           3    164.26     15.78  (------*-----)
5           3    197.54      0.72                       (------*-----)
6           3    170.22      8.47      (-----*------)
                                   -------+---------+---------+---------
Pooled StDev =     7.48                  165       180       195

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                 1           2           3           4           5

       2      -26.26
               14.77

       3      -27.31      -21.56
               13.73       19.47

       4        6.52       12.26       13.31
               47.55       53.30       54.34

       5      -26.77      -21.02      -19.98      -53.80
               14.27       20.01       21.06      -12.77

       6        0.56        6.30        7.35      -26.48        6.81
               41.59       47.34       48.38       14.56       47.84
```

2. 3 :Variate: Grain weights for Experiment 1, Date 3

```
Analysis of Variance for C4
Source     DF        SS        MS        F        P
C1          5    3881.8     776.4    39.66    0.000
Error      12     234.9      19.6
Total      17    4116.7
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -------+---------+---------+---------
1           3    186.36      5.61                    (--*---)
2           3    194.82      4.41                         (---*---)
3           3    191.97      3.53                       (---*---)
4           3    163.69      3.89    (---*---)
5           3    196.21      0.15                          (---*---)
6           3    160.22      6.23  (---*---)
                                   -------+---------+---------+---------
Pooled StDev =     4.42                 165       180       195

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                 1           2           3           4           5

       2     -20.593
               3.673

       3     -17.740      -9.280
               6.527      14.987

       4      10.537      18.997      16.143
              34.803      43.263      40.410

       5     -21.977     -13.517     -16.370     -44.647
               2.290      10.750       7.897     -20.380

       6      14.010      22.470      19.617      -8.660      23.853
              38.277      46.737      43.883      15.607      48.120
```

Appendix 3: Data analysis for Frass Weight: Experiment 1: MINITAB 13 ONE WAY ANOVA

3. 4 Variate: Frass weights for Experiment 1, Date 1

```
Analysis of Variance for Frass we
Source     DF        SS        MS        F        P
Treatmen    5    15.059     3.012     6.31    0.004
Error      12     5.726     0.477
Total      17    20.785
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ----+---------+---------+---------+--
1           3    1.3867    0.6461         (-----*-----)
2           3    1.3800    0.7871         (-----*-----)
3           3    0.7833    0.9324     (-----*-----)
4           3    3.0800    0.4232                    (-----*----)
5           3    0.3280    0.4332  (-----*-----)
6           3    2.2867    0.7679               (-----*-----)
                                   ----+---------+---------+---------+--
Pooled StDev =   0.6908              0.0       1.5       3.0       4.5

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                1           2           3           4           5

       2     -1.8877
              1.9010

       3     -1.2910     -1.2977
              2.4977      2.4910

       4     -3.5877     -3.5943     -4.1910
              0.2010      0.1943     -0.4023

       5     -0.8357     -0.8423     -1.4390      0.8577
              2.9530      2.9463      2.3497      4.6463

       6     -2.7943     -2.8010     -3.3977     -1.1010     -3.8530
              0.9943      0.9877      0.3910      2.6877     -0.0643
```

3. 4: Variate: Frass weights for Experiment 1, Date 2

```
Analysis of Variance for Frass we
Source     DF        SS        MS        F        P
Treatmen    5   197.190    39.438    50.67    0.000
Error      12     9.340     0.778
Total      17   206.530
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -+---------+---------+---------+-----
1           3     4.367     1.468               (---*--)
2           3     2.527     0.445         (--*---)
3           3     0.987     0.176    (--*---)
4           3     9.483     0.514                                (---*--)
5           3     2.797     0.887          (--*---)
6           3     9.267     1.111                               (---*---)
                                   -+---------+---------+---------+-----
Pooled StDev =    0.882           0.0       3.0       6.0       9.0

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                 1           2           3           4           5

       2      -0.579
               4.259

       3       0.961      -0.879
               5.799       3.959

       4      -7.536      -9.376     -10.916
              -2.697      -4.537      -6.077

       5      -0.849      -2.689      -4.229       4.267
               3.989       2.149       0.609       9.106

       6      -7.319      -9.159     -10.699      -2.203      -8.889
              -2.481      -4.321      -5.861       2.636      -4.051
```

3. 4 Variate: Frass weights for Experiment 1, Date 3

```
Analysis of Variance for Frass we
Source     DF        SS        MS        F        P
Treatmen    5    429.31     85.86    21.63    0.000
Error      12     47.64      3.97
Total      17    476.95
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -+---------+---------+---------+-----
1           3     5.720     2.218         (----*----)
2           3     3.933     1.052      (----*----)
3           3     2.027     2.684  (----*----)
4           3    12.483     2.576                     (----*----)
5           3     2.270     0.295   (----*----)
6           3    14.423     1.967                         (----*----)
                                   -+---------+---------+---------+-----
Pooled StDev =    1.992           0.0       5.0      10.0      15.0

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                 1           2           3           4           5

       2      -3.677
               7.251

       3      -1.771      -3.557
               9.157       7.371

       4     -12.227     -14.014     -15.921
              -1.299      -3.086      -4.993

       5      -2.014      -3.801      -5.707       4.749
               8.914       7.127       5.221      15.677

       6     -14.167     -15.954     -17.861      -7.404     -17.617
              -3.239      -5.026      -6.933       3.524      -6.689
```

Appendix 4: Data analysis for Grain weight: Experiment 2 MINITAB 13 ONE-WAY ANOVA

4. 5: Variate: Grain weights for Experiment 2, Date 1

```
Analysis of Variance for Grain we
Source     DF        SS        MS        F        P
Treatmen    5   189.474    37.895    63.22    0.000
Error      12     7.193     0.599
Total      17   196.666
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---------+---------+---------+-------
1           3   198.130     0.689                          (--*---)
2           3   198.597     0.367                            (--*--)
3           3   198.397     0.479                           (--*---)
4           3   193.263     1.440            (--*--)
5           3   198.983     0.471                             (--*---)
6           3   190.493     0.680   (--*--)
                                   ---------+---------+---------+-------
Pooled StDev =    0.774                 192.0     195.0     198.0

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                1          2          3          4          5

       2     -2.590
              1.657

       3     -2.390     -1.923
              1.857      2.323

       4      2.743      3.210      3.010
              6.990      7.457      7.257

       5     -2.977     -2.510     -2.710     -7.843
              1.270      1.737      1.537     -3.597

       6      5.513      5.980      5.780      0.647      6.367
              9.760     10.227     10.027      4.893     10.613
```

4. 5: Variate: Grain weights for Experiment 2, Date 2

```
Analysis of Variance for Grain we
Source     DF        SS        MS        F        P
Treatmen    5   109.604    21.921    25.97    0.000
Error      12    10.131     0.844
Total      17   119.735
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --------+---------+---------+--------
1           3   194.467     0.725              (---*---)
2           3   196.390     1.242                     (---*--)
3           3   197.427     0.966                        (---*---)
4           3   190.783     1.013  (---*---)
5           3   198.140     0.779                           (--*---)
6           3   193.987     0.656             (---*--)
                                   --------+---------+---------+--------
Pooled StDev =    0.919                 192.0     195.0     198.0

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                 1           2           3           4           5

       2     -4.4431
              0.5964

       3     -5.4798     -3.5564
             -0.4402      1.4831

       4      1.1636      3.0869      4.1236
              6.2031      8.1264      9.1631

       5     -6.1931     -4.2698     -3.2331     -9.8764
             -1.1536      0.7698      1.8064     -4.8369

       6     -2.0398     -0.1164      0.9202     -5.7231      1.6336
              2.9998      4.9231      5.9598     -0.6836      6.6731
```

4. 5: Variate: Grain weights for Experiment 2, Date 3

```
Analysis of Variance for Grain we
Source     DF        SS        MS        F        P
Treatmen    5   3290.99    658.20    66.80    0.000
Error      12    118.24      9.85
Total      17   3409.23
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --------+---------+---------+--------
1           3    187.57      2.30                      (--*---)
2           3    191.83      3.60                          (--*--)
3           3    190.73      3.02                         (--*--)
4           3    164.56      2.63    (--*--)
5           3    196.65      0.68                               (--*--)
6           3    162.63      4.93  (---*--)
                                   --------+---------+---------+--------
Pooled StDev =     3.14                 168       180       192

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                 1           2           3           4           5

       2     -12.868
               4.348

       3     -11.775      -7.515
               5.442       9.702

       4      14.395      18.655      17.562
              31.612      35.872      34.778

       5     -17.695     -13.435     -14.528     -40.698
              -0.478       3.782       2.688     -23.482

       6      16.325      20.585      19.492      -6.678      25.412
              33.542      37.802      36.708      10.538      42.628
```

Appendix 5: Data analysis for Frass Weight: Experiment 2: MINITAB 13 ONE WAY ANOVA

5. 6: Variate: Frass weights for Experiment 2, Date 1

```
One-way ANOVA: Frass weight (g)1 versus Treatments

Analysis of Variance for Frass we
Source     DF        SS        MS        F        P
Treatment   5    20.162     4.032     9.36    0.001
Error      12     5.170     0.431
Total      17    25.332
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
1           3    1.6867    0.1721           (----*-----)
2           3    0.4603    0.4517   (----*-----)
3           3    1.0633    0.3868       (----*-----)
4           3    3.5967    1.4416                        (-----*----)
5           3    0.6733    0.2043    (----*-----)
6           3    2.1300    0.2858              (----*-----)
                                   ---+---------+---------+---------+---
Pooled StDev =   0.6564             0.0       1.5       3.0       4.5

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                 1           2           3           4           5

       2     -0.5737
              3.0264

       3     -1.1767     -2.4030
              2.4234      1.1970

       4     -3.7100     -4.9364     -4.3334
             -0.1100     -1.3363     -0.7333

       5     -0.7867     -2.0130     -1.4100      1.1233
              2.8134      1.5870      2.1900      4.7234

       6     -2.2434     -3.4697     -2.8667     -0.3334     -3.2567
              1.3567      0.1304      0.7334      3.2667      0.3434
```

5. 6: Variate: Frass weights for Experiment 2, Date 2

One-way ANOVA: Frass weight (g) 2 versus Treatments

```
Analysis of Variance for Frass we
Source     DF        SS        MS        F        P
Treatmen    5     76.12     15.22     6.86    0.003
Error      12     26.65      2.22
Total      17    102.78
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --+---------+---------+---------+----
1           3     4.397     1.639             (-------*------)
2           3     2.280     1.384     (------*-------)
3           3     1.743     1.564  (-------*------)
4           3     7.050     2.324                        (------*-------)
5           3     1.550     0.399  (------*-------)
6           3     5.493     0.846                 (-------*------)
                                   --+---------+---------+---------+----
Pooled StDev =    1.490            0.0       2.5       5.0       7.5

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                 1           2           3           4           5

       2      -1.970
               6.204

       3      -1.434      -3.550
               6.740       4.624

       4      -6.740      -8.857      -9.394
               1.434      -0.683      -1.220

       5      -1.240      -3.357      -3.894       1.413
               6.934       4.817       4.280       9.587

       6      -5.184      -7.300      -7.837      -2.530      -8.030
               2.990       0.874       0.337       5.644       0.144
```

5. 6: Variate: Frass weights for Experiment 2, Date 3

```
One-way ANOVA: Frass weight (g) 3 versus Treatments

Analysis of Variance for Frass we
Source     DF        SS        MS        F        P
Treatmen    5    476.51     95.30    62.04    0.000
Error      12     18.43      1.54
Total      17    494.94
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---------+---------+---------+-------
1           3     5.427     1.288         (--*--)
2           3     3.963     0.931      (--*--)
3           3     2.663     0.873   (--*--)
4           3    14.353     0.906                          (--*--)
5           3     2.310     0.678   (--*--)
6           3    14.240     2.156                         (--*---)
                                   ---------+---------+---------+-------
Pooled StDev =    1.239                  5.0      10.0      15.0

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00569

Critical value = 4.75

Intervals for (column level mean) - (row level mean)

                 1           2           3           4           5

       2    -1.936
             4.862

       3    -0.636      -2.099
             6.162       4.699

       4   -12.326     -13.789     -15.089
            -5.528      -6.991      -8.291

       5    -0.282      -1.746      -3.046       8.644
             6.516       5.052       3.752      15.442

       6   -12.212     -13.676     -14.976      -3.286     -15.329
            -5.414      -6.878      -8.178       3.512      -8.531
```

Appendix 6: T-tests on Grain Weight for seed varieties from different seed companies with different grain protectants for Experiment 3: GENSTAT 14 t-test

6. 7 Variate: Grain weights for Experiment 3, Date 1, PSZM521

Two-sample t-test

Variates: T1, UT1.

Test for equality of sample variances
Test statistic F = 143.58 on 2 and 2 d.f.
Probability (under null hypothesis of equal variances) = 0.01

Note: evidence of unequal sample variances -
variances estimated separately for each group.

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T1	3	197.6	0.86	0.929	0.536
UT1	3	175.9	123.90	11.131	6.426

Difference of means: 21.733

Standard error of difference: 6.449

95% one-sided confidence interval for difference in means: (3.078, ...)

Test of null hypothesis that mean of T1 is not greater than mean of UT1
Test statistic t = 3.37 on approximately 2.03 d.f.
Probability = 0.038

Identifier	Minimum	Mean	Maximum	Values	Missing
T1$[_index_]	167.0	168.9	171.5	3	0

Identifier	Minimum	Mean	Maximum	Values	Missing
UT1$[_index_]	164.5	166.6	168.9	3	0

6. 7 Variate: Grain weights for Experiment 3, Date 1, AC71

Two-sample t-test

Variates: T1, UT1.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.
Test for equality of sample variances

Test statistic F = 1.11 on 2 and 2 d.f.
Probability (under null hypothesis of equal variances) = 0.95

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T1	3	168.9	5.331	2.309	1.333
UT1	3	166.6	4.821	2.196	1.268

Difference of means: 2.293
Standard error of difference: 1.840

95% one-sided confidence interval for difference in means: (-1.628, ...)

Test of null hypothesis that mean of T1 is not greater than mean of UT1

Test statistic t = 1.25 on 4 d.f.

Probability = 0.140

Identifier	Minimum	Mean	Maximum	Values	Missing
T1$[_index_]	194.8	195.5	196.3	3	0

Identifier	Minimum	Mean	Maximum	Values	Missing
UT1$[_index_]	170.0	171.2	172.2	3	0

6. 7: Variate: Grain weights for Experiment 3, Date 1, PHB30G19

Two-sample t-test

Variates: T1, UT1.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 2.02 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.66

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T1	3	195.5	0.6345	0.7966	0.4599
UT1	3	171.2	1.2825	1.1325	0.6538

Difference of means:	24.287
Standard error of difference:	0.799

95% one-sided confidence interval for difference in means: (22.58, ...)

Test of null hypothesis that mean of T1 is not greater than mean of UT1
Test statistic t = 30.38 on 4 d.f.

Probability < 0.001

Identifier	Minimum	Mean	Maximum	Values	Missing
T1$[_index_]	163.9	176.3	197.8	3	0

Identifier	Minimum	Mean	Maximum	Values	Missing
UT1$[_index_]	169.6	173.5	179.0	3	0

6. 7: Variate: Grain weights for Experiment 3, Date 1, PAN 53

Two-sample t-test

Variates: T1, UT1.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 14.40 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.13

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T1	3	176.3	350.1	18.71	10.803
UT1	3	173.5	24.3	4.93	2.847

Difference of means:	2.80
Standard error of difference:	11.17

95% one-sided confidence interval for difference in means: (-21.02, ...)

Test of null hypothesis that mean of T1 is not greater than mean of UT1

Test statistic t = 0.25 on 4 d.f.

Probability = 0.407

6. 7: Variate: Grain weights for Experiment 3, Date 2, PSZM521

Two-sample t-test
Variates: T, UT.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 1.37 on 2 and 2 d.f.
Probability (under null hypothesis of equal variances) = 0.84

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T	3	193.4	4.686	2.165	1.250
UT	3	166.7	3.426	1.851	1.069

Difference of means:	26.770
Standard error of difference:	1.644

95% one-sided confidence interval for difference in means: (23.26, ...)

Test of null hypothesis that mean of T is not greater than mean of UT

Test statistic t = 16.28 on 4 d.f.

Probability < 0.001

Identifier	Values	Missing	Levels
treatment	100	97	1

Identifier	Minimum	Mean	Maximum	Values	Missing
T$[_index_]	163.1	165.2	169.2	3	0

Identifier	Minimum	Mean	Maximum	Values	Missing
UT$[_index_]	161.5	163.5	165.1	3	0

6. 7: Variate: Grain weights for Experiment 3, Date 2, AC71

Two-sample t-test

Variates: T, UT.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 3.49 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.45

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T	3	165.2	11.964	3.459	1.997
UT	3	163.5	3.428	1.852	1.069

Difference of means: 1.680
Standard error of difference: 2.265

95% one-sided confidence interval for difference in means: (-3.149, ...)

Test of null hypothesis that mean of T is not greater than mean of UT

Test statistic t = 0.74 on 4 d.f.

Probability = 0.250

Identifier	Minimum	Mean	Maximum	Values	Missing
T$[_index_]	170.9	173.1	175.9	3	0

Identifier	Minimum	Mean	Maximum	Values	Missing
UT$[_index_]	165.2	167.7	169.7	3	0

6. 7: Variate: Grain weights for Experiment 3, Date 2, PHB30G19

Two-sample t-test

Variates: T, UT.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 1.23 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.90

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T	3	173.1	6.561	2.561	1.479
UT	3	167.7	5.343	2.311	1.335

Difference of means: 5.403
Standard error of difference: 1.992

95% one-sided confidence interval for difference in means: (1.157, ...)

Test of null hypothesis that mean of T is not greater than mean of UT

Test statistic t = 2.71 on 4 d.f.

Probability = 0.027

Identifier	Minimum	Mean	Maximum	Values	Missing
T$[_index_]	170.0	171.2	172.4	3	0

Identifier	Minimum	Mean	Maximum	Values	Missing
UT$[_index_]	160.0	168.9	174.6	3	0

6. 7: Variate: Grain weights for Experiment 3, Date 2, PAN 53

Two-sample t-test

Variates: T, UT.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 40.20 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.05

Note: evidence of unequal sample variances -
variances estimated separately for each group.

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T	3	171.2	1.50	1.226	0.708
UT	3	168.9	60.48	7.777	4.490

Difference of means: 2.283
Standard error of difference: 4.545

95% one-sided confidence interval for difference in means: (-10.57, ...)

Test of null hypothesis that mean of T is not greater than mean of UT

Test statistic t = 0.50 on approximately 2.10 d.f.

Probability = 0.332

6. 7: Variate: Grain weights for Experiment 3, Date 3, PSZM521

Two-sample t-test

Variates: T, UT.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 15.38 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.12

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T	3	186.3	5.59	2.364	1.365
UT	3	154.1	85.92	9.269	5.351

Difference of means:	32.190
Standard error of difference:	5.523

95% one-sided confidence interval for difference in means: (20.42, ...)

Test of null hypothesis that mean of T is not greater than mean of UT

Test statistic t = 5.83 on 4 d.f.

Probability = 0.002

Identifier	Minimum	Mean	Maximum	Values	Missing
T$[_index_]	157.4	159.0	160.6	3	0

Identifier	Minimum	Mean	Maximum	Values	Missing
UT$[_index_]	151.8	153.4	155.4	3	0

6. 7: Variate: Grain weights for Experiment 3, Date 3, AC71

Two-sample t-test

Variates: T, UT.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 1.31 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.87

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T	3	159.0	2.598	1.612	0.9305
UT	3	153.4	3.405	1.845	1.0654

Difference of means:	5.640
Standard error of difference:	1.415

95% one-sided confidence interval for difference in means: (2.624, ...)

Test of null hypothesis that mean of T is not greater than mean of UT

Test statistic t = 3.99 on 4 d.f.

Probability = 0.008

Identifier	Minimum	Mean	Maximum	Values	Missing
T$[_index_]	171.3	173.8	176.1	3	0

Identifier	Minimum	Mean	Maximum	Values	Missing
UT$[_index_]	165.7	167.7	169.1	3	0

6. 7: Variate: Grain weights for Experiment 3, Date 3, PHB30G19

Two-sample t-test

Variates: T, UT.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 1.84 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.70

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T	3	173.8	5.798	2.408	1.390
UT	3	167.7	3.154	1.776	1.025

Difference of means:	6.107
Standard error of difference:	1.727

95% one-sided confidence interval for difference in means: (2.424, ...)

Test of null hypothesis that mean of T is not greater than mean of UT

Test statistic t = 3.54 on 4 d.f.

Probability = 0.012

Identifier	Minimum	Mean	Maximum	Values	Missing
T$[_index_]	154.9	159.5	164.9	3	0

Identifier	Minimum	Mean	Maximum	Values	Missing
UT$[_index_]	152.6	156.0	158.9	3	0

6. 7: Variate: Grain weights for Experiment 3, Date 3, PAN 53

Two-sample t-test

Variates: T, UT.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 2.53 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.57

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T	3	159.5	25.16	5.016	2.896
UT	3	156.0	9.93	3.150	1.819

Difference of means: 3.517
Standard error of difference: 3.420

95% one-sided confidence interval for difference in means: (-3.774, ...)

Test of null hypothesis that mean of T is not greater than mean of UT

Test statistic t = 1.03 on 4 d.f.

Probability = 0.181

Appendix 7: T-tests on Grain Weight for Manica variety : treated and untreated: Experiment 4: GENSTAT 14.1 t-test

7. 8 Variate: Grain weights for Experiment 4, Date 1

Two-sample t-test

Variates: T, UT.

Test for equality of sample variances

Test statistic F = 1047.87 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.00
Note: strong evidence of unequal sample variances -
variances estimated separately for each group.

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T	3	199.1	0.3	0.561	0.324
UT	3	177.3	329.5	18.152	10.480

Difference of means: 21.76
Standard error of difference: 10.48

95% one-sided confidence interval for difference in means: (-8.819, ...)

Test of null hypothesis that mean of T is not greater than mean of UT
Test statistic t = 2.08 on approximately 2.00 d.f.
Probability = 0.087

Identifier	Minimum	Mean	Maximum	Values	Missing
T$[_index_]	196.9	197.5	198.0	3	0

Identifier	Minimum	Mean	Maximum	Values	Missing
UT$[!(1,2)]	197.5	197.7	198.0	2	0
Identifier	Minimum	Mean	Maximum	Values	Missing
UT$[_index_]	171.3	171.6	172.1	3	0

7. 8: Variate: Grain weights for Experiment 4, Date 2

Two-sample t-test

Variates: T, UT.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 1.77 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.72

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T	3	197.5	0.2809	0.5300	0.3060
UT	3	171.6	0.1591	0.3989	0.2303

Difference of means:	25.820
Standard error of difference:	0.383

95% one-sided confidence interval for difference in means: (25.00, ...)

Test of null hypothesis that mean of T is not greater than mean of UT

Test statistic t = 67.42 on 4 d.f.

Probability < 0.001

Identifier	Minimum	Mean	Maximum	Values	Missing
T$[_index_]	196.4	196.7	197.0	3	0

Identifier	Minimum	Mean	Maximum	Values	Missing
UT$[_index_]	145.7	154.7	165.7	3	0

7. 8: Variate: Grain weights for Experiment 4, Date 3

Two-sample t-test

Variates: T, UT.

Message: Sample size should be greater than 5 for a reliable t-test or confidence interval.

Test for equality of sample variances

Test statistic F = 1266.98 on 2 and 2 d.f.

Probability (under null hypothesis of equal variances) = 0.00

Note: strong evidence of unequal sample variances -
variances estimated separately for each group.

Summary

Sample	Size	Mean	Variance	Standard deviation	Standard error of mean
T	3	196.7	0.08	0.285	0.165
UT	3	154.7	102.92	10.145	5.857

Difference of means: 42.053
Standard error of difference: 5.860

95% one-sided confidence interval for difference in means: (24.96, ...)

Test of null hypothesis that mean of T is not greater than mean of UT

Test statistic t = 7.18 on approximately 2.00 d.f.

Probability = 0.009

Appendix 8: Data analysis for corrected LGB mortality: Experiment1 and Experiment 2: MINITAB 13 ONE WAY ANOVA

8. 9 Variate: Corrected LGB mortality for Experiment 1, Date 1

One-way ANOVA: d1 versus trt

```
Analysis of Variance for d1
Source     DF        SS        MS        F        P
trt         4    3.9228    0.9807    77.16    0.000
Error      10    0.1271    0.0127
Total      14    4.0499
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --+---------+---------+---------+----
1           3    1.7178    0.0736                        (--*--)
2           3    1.8802    0.0496                            (--*--)
3           3    1.7834    0.0312                          (--*--)
4           3    0.5550    0.2249  (--*--)
5           3    1.9072    0.0641                            (--*--)
                                   --+---------+---------+---------+----
Pooled StDev =   0.1127            0.50      1.00      1.50      2.00

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00818

Critical value = 4.65

Intervals for (column level mean) - (row level mean)

                 1           2           3           4

       2     -0.4651
              0.1403

       3     -0.3682     -0.2058
              0.2371      0.3995

       4      0.8602      1.0226      0.9257
              1.4655      1.6279      1.5311

       5     -0.4920     -0.3296     -0.4265     -1.6549
              0.1133      0.2757      0.1788     -1.0496
```

8. 9: Variate: Corrected LGB mortality for Experiment 1, Date 2

One-way ANOVA: d2 versus trt

```
Analysis of Variance for d2
Source     DF        SS        MS        F        P
trt         4    6.7896    1.6974    54.62    0.000
Error      10    0.3108    0.0311
Total      14    7.1004
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  -+---------+---------+---------+-----
1           3    1.7449    0.0134                        (--*--)
2           3    1.8738    0.0801                          (--*--)
3           3    1.7836    0.0352                        (--*---)
4           3    0.1620    0.3833  (--*---)
5           3    1.9392    0.0247                          (---*--)
                                   -+---------+---------+---------+-----
Pooled StDev =   0.1763           0.00      0.70      1.40      2.10

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00818

Critical value = 4.65

Intervals for (column level mean) - (row level mean)

                 1           2           3           4

       2     -0.6022
              0.3444

       3     -0.5120     -0.3831
              0.4346      0.5635

       4      1.1096      1.2385      1.1483
              2.0562      2.1851      2.0949

       5     -0.6675     -0.5386     -0.6288     -2.2504
              0.2790      0.4079      0.3177     -1.3039
```

8. 9: Variate: Corrected LGB mortality for Experiment 1, Date 3

One-way ANOVA: d3 versus trt

```
Analysis of Variance for d3
Source     DF        SS        MS        F        P
trt         4     4.244     1.061     8.52    0.003
Error      10     1.245     0.124
Total      14     5.489
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ----------+---------+---------+------
1           3    1.7026    0.1168                   (-----*------)
2           3    1.8133    0.1159                    (------*-----)
3           3    1.7844    0.0452                    (-----*------)
4           3    0.4774    0.7688  (------*-----)
5           3    1.8936    0.0484                      (-----*------)
                                   ----------+---------+---------+------
Pooled StDev =   0.3528                    0.70      1.40      2.10

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00818

Critical value = 4.65

Intervals for (column level mean) - (row level mean)

                 1          2          3          4

       2     -1.0580
              0.8365

       3     -1.0290    -0.9183
              0.8654     0.9762

       4      0.2779     0.3887     0.3597
              2.1724     2.2831     2.2542

       5     -1.1382    -1.0275    -1.0564    -2.3634
              0.7562     0.8670     0.8380    -0.4689
```

8. 9 Variate: Corrected LGB mortality for Experiment 2, Date 1

One-way ANOVA: d1 versus trt

```
Analysis of Variance for d1
Source     DF        SS        MS        F        P
trt         4   2.40002   0.60001   167.90    0.000
Error      10   0.03574   0.00357
Total      14   2.43576
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  --------+---------+---------+--------
1           3    1.7927    0.0163                             (-*-)
2           3    1.8566    0.0926                               (-*-)
3           3    1.8347    0.0309                              (-*--)
4           3    0.8508    0.0519  (-*--)
5           3    1.9032    0.0734                                (-*--)
                                   --------+---------+---------+--------
Pooled StDev =   0.0598                 1.05      1.40      1.75

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00818

Critical value = 4.65

Intervals for (column level mean) - (row level mean)

                 1           2           3           4

       2   -0.2243
            0.0967

       3   -0.2025     -0.1387
            0.1185      0.1823

       4    0.7815      0.8453      0.8235
            1.1025      1.1663      1.1445

       5   -0.2709     -0.2071     -0.2289     -1.2129
            0.0501      0.1139      0.0921     -0.8919
```

8. 9 Variate: Corrected LGB mortality for Experiment 2, Date 2

One-way ANOVA: d2 versus trt

```
Analysis of Variance for d2
Source     DF        SS        MS        F        P
trt         4   5.41038   1.35259   261.01    0.000
Error      10   0.05182   0.00518
Total      14   5.46220
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ------+---------+---------+---------+
1           3    1.7725    0.1190                               (*-)
2           3    1.8515    0.0690                                (-*-)
3           3    1.7956    0.0126                               (-*-)
4           3    0.3370    0.0800   (-*-)
5           3    1.9141    0.0205                                  (-*-)
                                   ------+---------+---------+---------+
Pooled StDev =   0.0720                  0.50      1.00      1.50      2.00

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00818

Critical value = 4.65

Intervals for (column level mean) - (row level mean)

                 1           2           3           4

       2     -0.2722
              0.1143

       3     -0.2164     -0.1374
              0.1701      0.2491

       4      1.2423      1.3212      1.2654
              1.6288      1.7078      1.6519

       5     -0.3348     -0.2559     -0.3117     -1.7704
              0.0517      0.1307      0.0748     -1.3838
```

8. 9 Variate: Corrected LGB mortality for Experiment 2, Date 3

One-way ANOVA: d3 versus trt

```
Analysis of Variance for d3
Source     DF        SS        MS        F        P
trt         4   2.04652   0.51163    52.03    0.000
Error      10   0.09834   0.00983
Total      14   2.14487
                                   Individual 95% CIs For Mean
                                   Based on Pooled StDev
Level       N      Mean     StDev  ---+---------+---------+---------+---
1           3    1.5982    0.0410                     (--*--)
2           3    1.7752    0.1220                         (--*---)
3           3    1.6446    0.0324                      (--*--)
4           3    0.8349    0.1687   (--*--)
5           3    1.8800    0.0557                            (--*--)
                                   ---+---------+---------+---------+---
Pooled StDev =   0.0992              0.80      1.20      1.60      2.00

Tukey's pairwise comparisons

    Family error rate = 0.0500
Individual error rate = 0.00818

Critical value = 4.65

Intervals for (column level mean) - (row level mean)

                 1           2           3           4

       2     -0.4432
              0.0892

       3     -0.3126     -0.1356
              0.2198      0.3968

       4      0.4971      0.6741      0.5435
              1.0295      1.2065      1.0759

       5     -0.5480     -0.3710     -0.5016     -1.3113
             -0.0155      0.1615      0.0309     -0.7788
```