MAKERERE UNIVERSITY

EVALUATION OF MODIFIED COLLECTION DRUMS AND LIGHT EMITTING DIODE BULBS FOR TRAPPING THE EDIBLE LONG-HORNED GRASSHOPPER, *Ruspolia differens* (SERVILLE) IN UGANDA

BY

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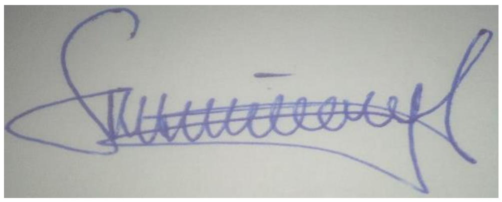
APRIL 2021

DECLARATION

I SENGENDO FRANCIS, hereby declare to the best of my knowledge that this dissertation is my own work, submitted to the School of Biosciences, College of Natural Sciences and that it has never been submitted to any tertiary institution or University for any award.

SENGENDO FRANCIS



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APPROVAL

This thesis has been submitted with our approval as supervisors.

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DEDICATION

I dedicate this work to my family for the support and all the sacrifices they offered to me during the course of this study.

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LIST OF ACRONYMS

ANOVA	Analysis of Variance
CDC	Centres for Disease Control
GLM	Generalised Linear Model
GPS	Geographical Positioning System
ICIPE	International Centre for Insect physiology and Ecology
LED	Light Emitting Diode
SDC	Swiss Agency for Development and Cooperation
SIDA	Swedish International Development Cooperation Agency
SPSS	Statistical Package for Social Sciences
UK	United Kingdom
US	United States
USD	United States Dollar
UV	Ultra Violet

ABSTRACT

The long-horned grasshopper (*Ruspolia differens*) is a delicacy in Uganda and many African countries. It is traditionally trapped at night during the swarming seasons using mercury bulbs that consume a lot of electric energy and pollute the environment. In addition, the collection drums used in the traditional trapping technique are non-selective, trapping non-target insects, some of which are allergenic to humans. Further, these traps are inefficient in retaining the insects. The International Centre of Insect Physiology and Ecology designed a modified *R. differens* collection drum by fitting a funnel to minimize escape of *R. differens* catches; and partitioning the drum into three compartments using meshes of varying sizes to filter bigger non-target insects at the top, *R. differens* in the middle and smaller insects at the bottom. The mercury bulbs traditionally used in attracting *R. differens* to the trap were replaced with LED bulbs to save electric energy and prevent the release of mercury into the environment. The objectives of this study were (i) to determine the effect of collection drum design and light source on the quantity of *R. differens* trapped in Masaka, (ii) determine the effect of collection drum design and light source on the number of non-target insects trapped along with *R. differens* in Masaka and (iii) carry out a cost-benefit analysis of using improved traps and the traditional traps for trapping *R. differens*. The study was conducted in Nyendo town Masaka district during April – May and repeated in November – December swarming seasons of 2019. Experiments were set at four trapping sites of commercial trappers and trapping was done for a total of fourteen effective nights which were spread out over the two swarming seasons. Experiments were overlaid with existing setups of commercial trappers which consisted of 16 to 20 traditional drums. Six drums were randomly selected from each site as experimental units, of which three were used as controls (3 replicates) and the other three were replaced with modified *R. differens* collection drums. Measurements of *R. differens* and counts of non-target species were taken from the three modified drums and three selected traditional drums from each site per night. Thirty randomly selected commercial trappers were interviewed to collect data on capital expenditures, operating costs and returns of the traditional technique; and these costs and returns were also estimated for the improved technique. Results show that the modified drums collected a comparable quantity of *R. differens* as the traditional drums, but with significantly reduced contamination from non-target insects (*Achaea* sp., *Haritalodes* sp., *Heteronychus* sp. and *Paederus* sp.) which were

smaller than *R. differens*. Most importantly, 85% of *Paederus* sp. (Nairobi fly) which is the most hazardous non-target insect was eliminated. The bottom wire mesh was found effective at filtering off non-target species smaller than *R. differens* to the bottom compartment. However, the upper wire mesh was not effective at filtering non-target species which were of the same size or bigger than *R. differens*. Light Emitting Diode bulbs of 400 W trapped a comparable quantity of *R. differens* as mercury bulbs of the same wattage, but the LED bulbs consumed less than half of the electric power compared to the mercury bulbs. Trapping *R. differens* using modified drums with LED 400 W bulbs was more profitable than the traditional drums with mercury 400 W. The improved technique comprising the modified drums and LED 400 W bulbs is therefore recommended as a better alternative for trapping cleaner *R. differens* while saving energy.

CHAPTER ONE: GENERAL INTRODUCTION

1. 1. Background

Insects are the most diverse organisms accounting for more than 70% of the existing species (Van-Huis, 2015; Kelemu et al., 2015). Traditionally, more than 2000 insect species are consumed worldwide at different stages of their life cycle, a practice known as entomophagy. According to Anankware et al., (2014), edible insects are highly nutritious i.e, they are good sources of proteins, fats, minerals, vitamins and energy. Their crude protein content is reported to be as high as 43% which is significantly higher than the conventional sources of proteins (Kinyuru et al., 2009). Insects are widely consumed in different parts of the world, most especially in Asia and Africa. About 524 insect species are consumed in Africa, 349 in Asia, 679 in America (mainly Central and South America), 152 in Australia and only 41 in Europe (Jongema, 2015). Apparently, Mexico has the highest number of edible insect species (Banjo and Songonuga, 2006) followed by Thailand, Congo, India, Australia, China and Zambia (Jongema, 2015).

In many African countries, a number of native edible insect species are harvested from the wild by different communities (Van-Huis et al., 2013). In Uganda, insect species commonly used as food include; long-horned grasshoppers (*Ruspolia differens*), palm weevils (*Rhynchophorus phoenicis*) larvae and termites (*Macrotermes* spp), (Okia et al., 2017). *Ruspolia differens* and *Macrotermes* spp swarm seasonally and people trap them during swarming using traditional traps. *Ruspolia differens* is widely harvested and consumed as a traditional snack in Zambia, Democratic Republic of Congo, Tanzania, Uganda and Kenya but mostly consumed in Uganda and Tanzania (Mmari et al., 2017).

In Uganda, *R. differens* swarms from March to May and November to December (Agea et al., 2008; Ssepuuya et al., 2016). In the past, during the swarming seasons, *R. differens* were collected in different parts of the country by hand picking from vegetation and later traps were designed by the traditional people in Masaka district (the renowned area for trapping *R. differens* in Uganda), currently, harvesting *R. differens* is a lucrative business (Agea et al., 2008). According to Mr. Kuraish Katongole (personal communication), the chairperson of Old Masaka Basenene Association of Uganda Limited which is registered by Uganda Registration Services Bureau (Registration No. 80010003846165), approximately 800 people in the district are employed at different levels of the *R. differens* value chain including trapping, transporting, wholesale, processing and retailing. According to Agea et al. (2008), *R. differens* trade in Uganda generated over US $ 220 per person (traders or sellers) during the swarming season in 2007. The traditional traps used to trap *R. differens* consist of high wattage mercury bulbs (250 – 1000 W), metallic drums for collecting the insects and iron sheets that direct them into the drums (Okia et al., 2017). Similar traps consisting of folded iron sheets, large plastic buckets and three very bright light bulbs of 400 Watts each are used to trap *R. differens* in Tanzania (Mmari et al., 2017).

The high wattage mercury bulbs used are dangerous to the people using them and to the environment. The bulbs emit mercury into the air which then enters the ecosystems. This later accumulates in the food chains following its consumption by different organisms hence leading to its bio accumulation (Lim et al., 2012). According to Bibha and Ranjana (2015), mercury can enter the body through the lungs, skin and the digestive system. Once in the human body, mercury acts as a neurotoxin, interfering with the brain and nervous system. In addition, it causes irritation of the skin and eyes (Okia et al., 2017). This puts commercial trappers of *R. differens* at a high health risk. The bulbs also increase the costs for trapping *R. differens* due to high consumption of electricity. In addition, the drums are non-selective, collecting along many non-target insect species which contaminate the harvest and they are inefficient at retaining *R. differens*. Some of the non-target insects secrete chemicals into grasshoppers, for example the Nairobi fly (*Paederus sabaeus*) secretes pederine which causes temporary blindness and dermatitis to people who get into contact with it (Iserson and Walton, 2012). However, the performance of these drums remains to be investigated and no alternatives have been documented. To address the aforementioned challenges associated with the traditional drums used in trapping *R. differens* in Uganda, *R. differens* collection drums were modified to filter off non-target insect species and increase retention of *R. differens* without using foreign substances.

1.2. Modifications made on *R. differens* collection drum

Clean empty drums (TRWY, TRWY container LTD, Shandong China) of 200 litres capacity with a 0. 57 m diameter opening on the top cover were fitted with funnels made from plain iron sheets to minimize escape of the catches (Figure 1.1). The drums were vertically partitioned into three compartments; upper (0.35 m height), middle (0.35 m height) and bottom (0.15 m height) using wire meshes. A 6 × 6 mm wire mesh was designed to retain non-target insects that are bigger than

R. differens in the upper compartment and a 3 × 3 mm mesh was fitted to retain *R. differens* in the middle compartment while filtering smaller non-target insects to the bottom compartment. Doors of 0.1 m × 0.2 m were fitted on each compartment in the same vertical line along the drums to facilitate collection of the catch from each compartment.

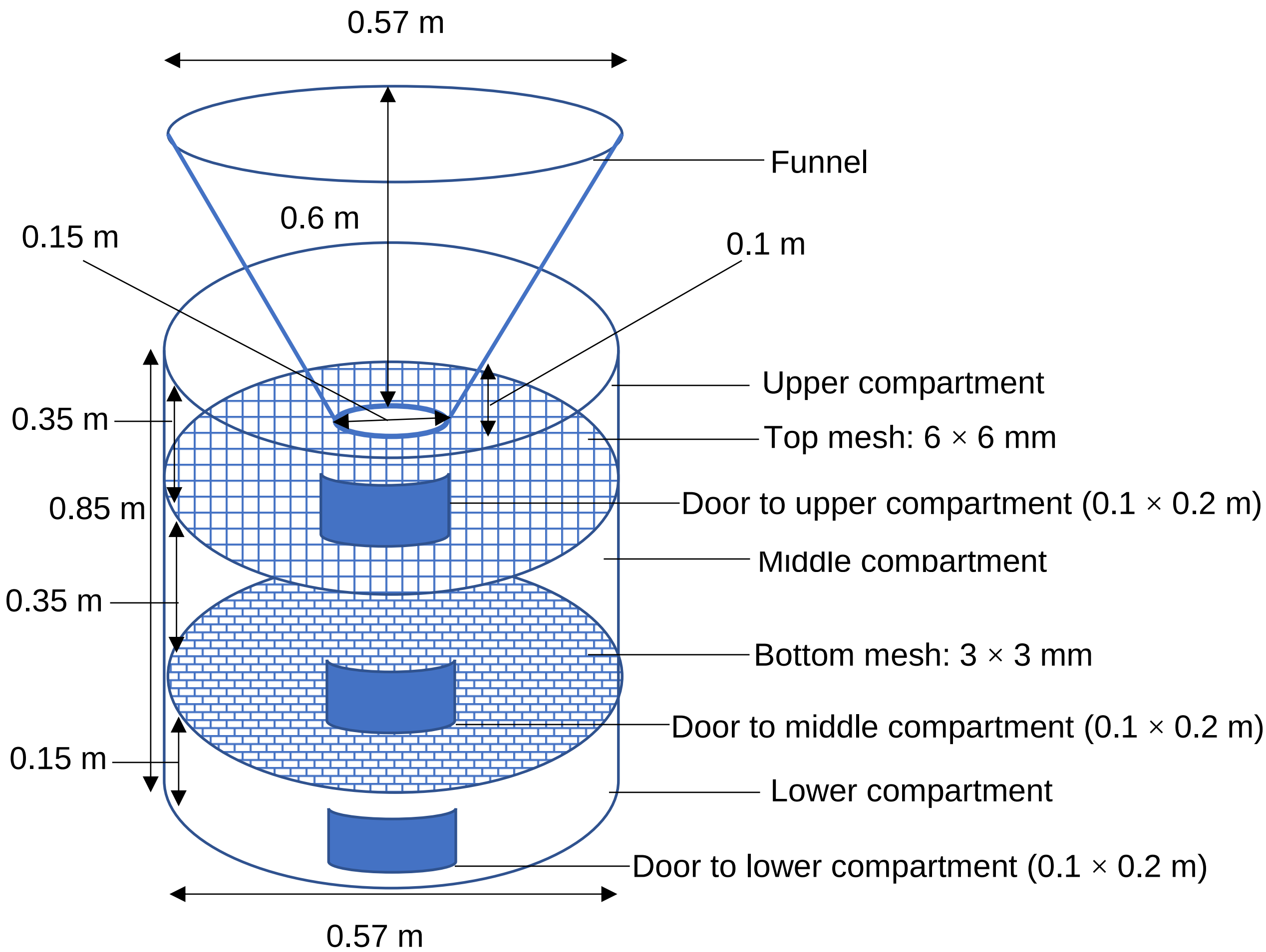

Figure 1.1: Schematic design of the modified *R. differens* collection drum

Over the last decade, the Light Emitting Diode (LED) bulbs have become increasingly popular as a replacement for standard incandescent bulbs or fluorescent bulbs. This is because they consume about 85% less energy than mercury bulbs, produce less heat, durable and are less hazardous to humans and the environment (Lim et al., 2012). LED bulbs are also a much more focused light sources with a narrow spectrum of light about 5 nm (Green et al., 2012). This allows for specific lighting characteristics to be selected and tailored for a specific purpose.

1.3. Statement of the problem

Trapping of *R. differens* is done using traditional light traps which are associated with a number of challenges. For example, during trapping, the grasshoppers can easily fly out of the collection drums and in order to prevent them from getting out of the drums, commercial trappers sprinkle cassava flour, waste oils and water into the drums (Okia et al., 2017). This may compromise the quality of *R. differens* caught and the quantity is also low because some catches escape from the drums. Catches in these drums are a mixture of grasshoppers and the non-target species which may be harmful to humans. Also, the bulbs used to attract *R. differens* are of high wattage (250 – 1000 W), which consume a lot of electricity resulting into high electricity bills and short bulb life span (Bibha and Ranjana, 2015). This consequently reduces the profits that would have been obtained from the grasshopper catches. Moreover, the mercury bulbs also release mercury which is associated with negative long-term effects to the environment and on the sight and the general health of trappers and other people around the trapping sites (Lim et al., 2012). Despite the challenges associated with the traditional technique of trapping *R. differens*, no studies have been carried out to address them and improve on the trapping technique. Therefore, there is need to develop improved methods of trapping *R. differens*. Alternatives to mercury bulbs are the Light Emitting Diodes (LED) bulbs. According to Cohnstaedt et al., (2008), LED bulbs increased capture rates of sandflies by 50%. In addition, Silva et al., (2016) reported that LED-baited suction traps were more efficient than incandescent-baited traps in trapping sand flies. However, the effectiveness of LED bulbs in attracting other insects like *R. differens* has not been investigated. Here, modified drums were designed to prevent escape of the trapped insects and also filter off non-target species that are smaller or bigger than *R. differens*. The effectiveness of these modified drums and LED bulbs in trapping of *R. differens* as a pre-requisite for improving the trapping method of *R. differens* in Uganda have not previously been investigated.

1.4. Objectives

1.4.1. General objective

To assess the performance of collection drums and light emitting diode (LED) bulbs in trapping *R. differens* in Uganda in order to reduce the negative effects of the traditional trapping method and improve on its efficiency and hence increase the profitability of the business.

1.4.2. Specific objectives

i. To determine the effect of collection drum design and light source on the weight of *R. differens* trapped in Masaka.

i. To determine the effect of collection drum design and light source on the number of non-target insects trapped along with *R. differens* in Masaka.

ii. To carry out a cost-benefit analysis of using the improved and traditional technique for trapping *R. differens* in Masaka.

1.5. Hypotheses

i. The weight of *R. differens* caught from the modified and traditional drums is not different

ii. The weight of *R. differens* caught using 200 W LED, 100 W LED and 400 W mercury bulbs is not different

iii. The number of non-target insects caught with *R. differens* in the modified and traditional drums is not different

iv. The number of non-target insects caught with *R. differens* using 200 W LED, 100 W LED and 400 W mercury bulbs is not different

v. Using modified drums and LED bulbs for trapping *R. differens* is not as profitable as using the traditional drums and mercury bulbs

1.6. Justification

Harvesting of *R. differens* in Uganda has been traditionally done for generations. In villages, *R. differens* are hand-picked from the vegetation especially by women and children (Agea et al., 2008), while in towns, the grasshoppers are trapped at night using traditional light traps (Ssepuuya et al., 2016). These traditional collection methods, especially the light traps need to be improved since trapping of *R. differens* during the swarming seasons has become a big business in different parts of Uganda. It is important to develop better trapping methods that can increase on the quantity of *R. differens* caught, are cost effective and with less health hazards to humans and the environment. The modified drums tested in this study could reduce the use of contaminants like waste cooking oil and cassava flour that are applied in the traditional drums to increase retention *R. differens* (Okia et al., 2017). The modified drums could also reduce contamination of *R. differens* by reducing the number of non-target insects, hence preventing the health hazards associated with these non-target insects, for example the Nairobi flies which cause temporary blindness and dermatitis (Iserson and Walton, 2012). Light Emitting Diode bulbs tested in this study do not release mercury into the environment therefore they could prevent carcinogenic effects of mercury to the trappers and other people around the trapping sites (Ganesan et al., 2017). Light Emitting Diode bulbs could also reduce on electricity consumption (Lim et al., 2012), hence lowering the cost of electricity and increasing the profits obtained from the harvesting business. Information generated by the study could trigger more research towards improving the sustainability of trapping *R. differens.*

CHAPTER TWO: LITERATURE REVIEW

2.1. Taxonomy, biology and ecology of *R. differens*

Ruspolia differens, commonly known as "Nsenene", in Luganda belongs to order; Orthoptera, family; Tettigoniidae, genus; *Ruspolia*, and species; *differens*, hence the name *R. differens* (Agus, 2001). The family Tettigoniidae has more than 6,400 species which are characterized by long filiform antennae normally exceeding their body lengths. Species in this family share many characteristics but each has unique characteristics that can be used to distinguish it from others (Matojo and Hosea, 2013). For example: *R. differens* can be distinguished from its closest relative *Ruspolia nitidula* and other tettigoniids by; its swarming characteristic, colour polymorphism, male metathoracic flaps, paired subequal black markings on the mid and hind tibia, and a white inter-ocular oval mark that appears like a simple eye (Matojo, 2020).

Ruspolia differens is a slender insect of about 4-6.5 cm long with an elongated cone-shaped head, powerful chewing mouth parts with yellow jaw bases. *R. differens* is oviparous and it undergoes an incomplete metamorphosis with a high variability in sex ratio and color polymorphism (Matojo and Hosea, 2013). *Ruspolia differens* is an iteparous insect with two overlapping generations (G1 and G2) and it exists in either the swarming phase or the non-swarming phase (Matojo and Njau, 2010). Each of these generations have a total longevity of about one year, that is April-May (G1) and November-October (G2) (Matojo and Yarro, 2010).

The eggs that initiate G1 are laid in batches within haulms of grasses between April-May by G2 swarming adults. During dry spells, development is arrested at an early stage and resumes when favourable conditions prevail (Matojo and Njau 2010). Embryogenesis, development and nymphal emergence starts from the time of swarming and continues up to October. This gives rise to the non-swarming emerging adults which eventually give rise to the G1 swarming phase (adults) in mid-November to late-December. According to Matojo and Njau (2010), most individuals of the swarming phase suffer predation particularly by human, birds, small mammals and other animals. A few remaining individuals are then transformed into the non-swarming individuals in January to mid-February where most of them die out because of senescence and this marks the end of this generation. The G1 non-swarming adults coexist with enormous number of nymphs, which mainly arise from the eggs oviposited by the previous swarming phase of November-December.

Embryogenesis and nymphal emergence start from mid-February to mid-March (Matojo and Njau 2010). This is followed by a two-month nymphal development which gives rise to the non-swarming emerging adults during mid-March to Mid-April. These are then synchronized by acoustic communications into swarms in mid-April to late May, hence giving rise to generation two swarming phase (Matojo and Njau 2010). However according to Mmari et al., (2017), the origin of *R. differens* is still a mystery among the traditional communities. Mmari et al., (2017) also reported that the catches of *R. differens* have consistently reduced over time as the swarms reduce. This is due to the destruction of their natural habitats and changes in climate which result from human activities. Therefore, there is need to protect the natural habitats of *R. differens* and also domesticate them as recommended by Ssepuuya et al., (2018a). There is also a need to use traps that can efficiently trap *R. differens* in order to benefit from the small swarms but these are not yet developed.

Ruspolia differens is widespread from south west Africa through the Congo forests to South and East African countries. Countries where *R. differens* occurs include; Angola, Ghana, Ivory Coast, Central African Republic, Zaire, Rwanda, Kenya, Uganda, Tanzania, Rhodesia, Zanzibar, Mauritius, Madagascar. The insect is also found in some islands of the Indian Ocean (Agus, 2001, Massa, 2015). Ruspolia differens is a facultatively oligophagous grass-specialist which has a clear preference for certain grasses and sedges especially the inflorescences (Valtonen et al., 2018). In Uganda and Tanzania, *R. differens* swarms twice in a year with moderate swarms from April to June and high-density swarms from November to December (Agea et al., 2008, Matojo and Njau 2010). Studies on population density and seasonal swarming of *R. differens* by Matojo and Hosea (2013) indicated that swarming of this insect is highly predictable because they have adapted to match their swarms with the seasons of favourable conditions. They have adapted a permanent response to seasonal environmental changes, which is a unique character among the tettigoniids. However, the current changes in climate may reduce the size of swarms due to decreasing life resources like food, water and breeding grounds (Matojo and Hosea (2013). In addition, changes in rainfall patterns are suspected to alter the swarming seasons since *R. differens* adapts to swarm following rainfall seasons when environmental conditions are favourable (Matojo and Njau 2010). Matojo and Hosea (2013), reported that egg development and nymphal emergence occurs in March and October, as the rainy season commences. Then this gives rise to enormous swarms in April-May and November to December, the times when its basic life resources (food, water, shelter and breeding grounds) are optimum. During these swarming seasons they are exposed to predation and other factors that cause death. Then the insects that survive go into a non-swarming phase so that they can minimize overcrowding, competition and energy losses (Matojo and Hosea, 2013).

2.2. Technologies for trapping *R. differens*

During the swarming season, *R. differens* are harvested in different regions in Uganda, most especially in central, western regions and some districts in West Nile, mid-west and eastern (Ssepuuya et al., 2016). According to Agea et al., (2008), collection of *R. differens* in central Uganda was a tradition carried out by children and women. Women would get rewarded for trapping grasshoppers by their husbands who would buy for them a traditional wear known as 'Gomesi'. Today trapping of *R. differens* is a commercial activity which is done at night using traditional light traps that are made up of metallic drums, iron sheets and high wattage bulbs (250 – 1000 W) as a source of light (Agea et al., 2008). In Tanzania, trapping of *R. differens* is also done in a similar way. According to Mmari et al. (2017), traps used in Tanzania consist of; folded iron sheets, large buckets and three very bright light bulbs of 400 W each. The iron sheets are folded to a cone shape leading into a large bucket which collects the falling insects. During the night, smoke is set under the bright light, which confuses the insects hence hampering their ability to fly (Mmari et al., 2017).

The design of traps for *R. differens* are similar to light traps used to trap nocturnal beetles and moths. A typical example is the box trap which is constructed in such a way that it has five solid surfaces, with the sixth surface made up of two overlapping sheets of glass that are sloping inward to form a narrow horizontal aperture (Duehl et al., 2011). The side opposite the sixth surface does not have any opening, hence preventing escape of trapped insects. On this trap, a bottle with desired killing agent or a spirit lamp might be used to kill the insects entering the trap. During trapping, insects are guided through the narrow slit-like opening between the two glass sheets into the box (Duehl et al., 2011).

There has not been any improvement in the design of the trap for *R. differens*, unlike other light traps for moths and mosquitoes. Examples of improved traps are the Funnel Traps. These are based on observations that insects attracted to a light source usually settle below it or fly around it until they fall down due to exhaustion (Watson, 2016). The most common improved type of funnel trap is the Hiestand trap which consists of an open electric light source. It also has a funnel leading into an open killing-bottle below it. Although there have been improvements, light traps operate in the same way and the general assumption is that insects get attracted to light and they fly towards the light source in a more or less purposeful manner. Watson (2016) observed that insects are attracted to a very small source of light at a distance in an isolated dark area but on nearing a brightly illuminated area, they cease to fly and settle down. Watson (2016) also observed that if the source of light is distant and the insects are still able to fly straight, they maintain a constant angle with the direction of light. But on nearing the light source, the insects change the direction of flight very rapidly thus they then move towards it in an ever-steepening spiral (Watson, 2016).

In the recent years, Light Emitting Diodes (LED) bulbs are being used as a replacement for incandescent bulbs in light traps (Cohnstaedt et al., 2008). Light Emitting Diode is a solid-state unit that converts electricity to light with minimal generation of heat, this makes it a very efficient source of light. LED color can range from UV (350 nm) to infrared (700 nm) depending on the chemical composition. The angle of dispersion or cone of illumination from the bulb depends on the bulb structure and ranges from very narrow (as with laser pointers) to more broadly diffuse. Brightness level is determined by the electrical current passing through the LED (Cohnstaedt et al., 2008). Higher current produces brighter light, but the longevity of the bulbs is reduced. A LED bulb will function for several thousand hours if not subjected to electrical overload. The solid-state design of the LEDs makes them durable under field conditions and they are difficult to shatter and rarely need to be replaced (Cohnstaedt et al., 2008).

In the current application, Light Emitting Diode technology has been integrated into Center for Disease Control (CDC) light traps in 2 innovative modes. The first is the creation of a combo LED light bulb replacement for the current incandescent CDC light traps (Price and Baker, 2016). The second is a platform-based design for use of LEDs in a modified CDC light trap body. Both lighting designs allow for flexibility in the selection of the number of LED bulbs (4 – 16) with varying colors, viewing angles, or light intensity (Price and Baker, 2016). According to Cohnstaedt et al., (2008) specific lighting arrangements of LED bulbs can be used to maximize either capture rates or battery life, depending on the field of application. Incandescent bulbs produce a broad spectrum of light but LEDs can be selected to emit a narrow bandwidth or specific color (Mellor and Hamilton, 2003).

Previous studies by Burkett and Butler (2005), showed that mosquitoes, sand flies and Culicoide flies are attracted to light from LED bulbs. However, the effectiveness of LED bulbs in attracting orthopterans, for example *R. differens* has not been tested. LED bulbs are advantageous in that they can be changed quickly in the field to configure the trap to the particular needs of a trapping environment and they also have a low power consumption (Cohnstaedt et al., 2008). According to Lim et al., (2012), LED bulbs are less destructive to the environment and they have less human health hazards compared to incandescent and compact fluorescent bulbs. Zemel et al., (2017) also noted that LED are potential insect collecting devices due to their long-life span, and low power needs. Moreover, LEDs are available in many different wavelengths, allowing for potential specificity in the insects attracted (Zemel et al., 2017).

The effectiveness of light traps is normally affected by light from other sources like security lights, especially if the traps are used near settlements or in cities and towns (Watson 2016). Light from the moon also reduces the quantity of insects caught by light traps depending on the brightness of the moon because moon light masks the light from traps (Watson, 2016). Duehl et al., (2011), reported that light-trap catches of many species are affected by moon light. During the study, they observed that catches were less at full moon and this was attributed to competition of the trap light with moonlight. Other factors like; the direction and strength of the wind, weather, vegetation, season and design of the trap also affect the effectiveness of light traps (Duehl et al., 2011). Price and Baker, (2016), reported that LED bulbs were found effective in trapping nine insect orders including orthopterans, this provides evidence that these bulbs can be used to attract *R. differens.* Lysakov et al., (2019), found blue LEDs of wavelength within 440-470 nm effective at trapping Locusts. However, the effectiveness of LED lamps in trapping of *R. differens* had not been studied. The collection drums currently used by commercial trappers are non-selective, collecting many non-target insects together with *R. differens*. The drums are also open at the top (Okia et al., 2017), which allows easy escape *R. differens*. Therefore, the drums need to be modified in order to increase on the quantity of *R. differens* harvested and reduce contamination from non-target species.

2.3. Economic significance of *R. differens*

Worldwide edible insects contribute to the economies of countries at different levels and also improve the incomes of people who are engaged in edible insect farming and wild harvesting. Kelemu et al (2015) reported that women are more active in the insect business especially in the processing and sales activities. This enables them to get money for basic expenditures like; food, clothing and education. According to Dobermann et al., (2017), export and import of insects for food plays a strong economic role throughout South-East Asia. The import market in Thailand alone is valued at 1.14 million USD per year. In South Korea, the market which includes insects for food, feed and medicine was valued at 141 million USD in 2017 with predictions that by 2020, it will have quadrupled to 564 million USD (Dobermann et al., 2017). In Tanzania, it was reported that during the swarming season for *R. differens*, there is high potential for women to get employment and generate income from *R. differens* production (Mmari et al., 2017).

In Uganda, trapping and marketing of *R. differens* are lucrative businesses during the swarming seasons (Agea et al., 2008). Many people are employed at different levels along the value chain of *R. differens*, including trapping, transporting, wholesaling, processing and retailing during the swarming seasons. According to Van-Huis et al., (2013), the market for *R. differens* is dominated by mainly wholesalers who buy it from collectors/trappers and sell to retailers who in turn sell to consumers. The value chain of *R. differens* is dominated by men and a majority are engaged in trapping and wholesaling (Van-Huis et al., 2013). Most people eat *R. differens* as a snack whereas others eat it as food, according to Agea et al., (2008), 48% of the respondents said that they like eating *R. differens* because it is nutritious and rich in vitamins, fats and proteins. Despite the fact that *R. differens* is a delicacy with a high potential of processing and using it as an ingredient in infant porridges, snacks and foods, efforts are not yet taken to exploit this potential (Nampewo, 2013). Other possible uses of *R. differens* like extraction of oil and using it in bakeries are also still un exploited. Processing of *R. differens* involves plucking off the wings and legs before steaming or deep flying them, but the wings and legs are not put to any use (Nassaga, 2019). The majority of traders of *R. differens* in Uganda generated over Uganda shillings 400,000 (≈ US $ 223.5) during the swarming season in 2007 (Agea et al., 2008). However, information on what the collectors/trappers invest in the business and what they earn is still scarce. Agea et al., (2008), reported an average income generated from one swarming season but there is no information on the cost effectiveness of the traditional trapping method.

CHARPTER THREE: GENERAL MATERIALS AND METHODS

3.1. Study area

The study was carried out in Masaka district, central Uganda, because it is the leading *R. differens* trapping site in Uganda (Agea et al., 2008; Ssepuuya et al., 2016). Trapping experiments were set up at four randomly selected sites of commercial trappersin Nyendo town. The coordinates of each trapping site were recorded using a geographical positioning system (GPS) (GARMIN eTrex 20X, Garmin Ltd, Olathe, Kansas, U.S.A.) and plottted on Arc Map using the Arc GIS software version 10.3 (Esri Eastern Africa Ltd, Naiobi, Kenya) (Figure 3.1).

Masaka district is bordered by Sembabule in the Northwest, Mpigi in the North, Rakai in the west and south and Kalangala district in the east. It has an estimated human population of over 297,004 (Uganda Bureau of Statistics, 2018). The district is about 37 Km from the equator towards the south and lies between latitudes 00' 45'' S and 00' 15'' N and longitudes 310' 00'' E and 320' 00'' W, with an average altitude of 1150 m above sea level. The district has a total area of about 6413.3 Km^2 of which 3214 Km^2 is land and 3199.3 Km^2 is open water, wetlands and marshlands, a total of 1,221 ha are under cultivation. The total gazetted forest estate in Masaka district is about 35,302 ha, constituting about 6.38% of the total land area of the district. Scattered natural forests are also found along the lake shores (Masaka district statistical abstract, 2016).

According to Masaka district planning unit, (2016), the Climate of Masaka district is tropical in nature due to its closeness to the equator. The rainfall pattern is bimodal with two rainy seasons and dry spells between July to August, and January to March. During the period of March to May, Masaka receives very heavy rainfall of up to 1,200 mm and the second rainy season occurs between September to December. The annual average rainfall is between 1,100 mm and 1,200 mm with 100 – 110 rainy days. The average maximum temperature does not exceed 26^{0}C and the minimum is not below 15^{0}C with almost equal length of day and night throughout the year. The relative humidity level ranges between 30% and 75% throughout the district with the exception of lakeshore areas where it rises to 80% (Masaka district statistical abstract, 2016).

Agriculture is the dominant economic activity in Masaka district with 69% of the population deriving their livelihoods from farming. Other economic activities in the district are fishing and trade (Masaka district statistical abstract, 2012). Trapping *R. differens* is another economic activity that is carried out in the area during the swarming seasons. Ssepuuya *et al.* (2016), reported that Masaka is one of the districts with big swarms of *R. differens* in April to May and November to December.

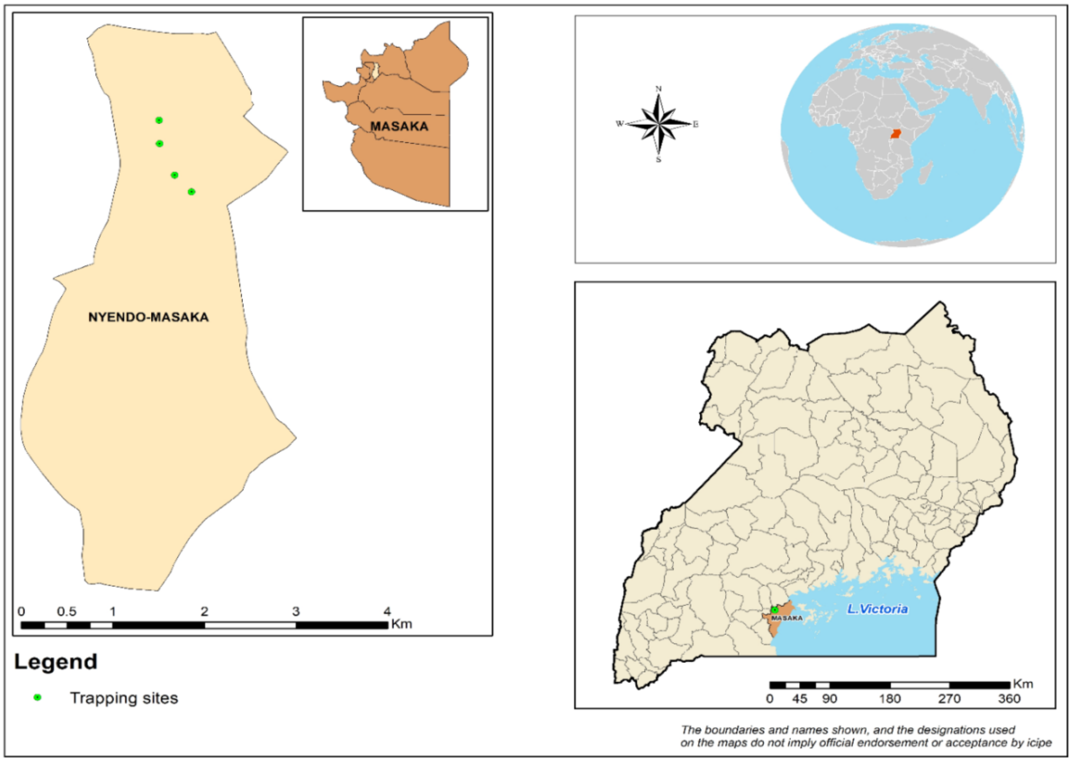

Figure 3.1: Location of the study area, Nyendo-Masaka in Uganda

3.2. Experimental design: First season

The trial was carried out during the swarming season from April to May 2019. Two wattages of LED bulbs (100 W and 200 W) (Cob, GS light, YAYE lighting company, Zhongshan, China) were compared with 400 W mercury bulb (GE lighting, Ningbo sunfine, lanxi qiming illumination company, Zhejiang, China) using traditional and modified drums at three commercial trapping sites. The trapping sites were set at 200–300 m apart to ensure similar topography and environmental conditions (Silva et al., 2016), but minimizing light spill over effects across sites. Three bulbs of the same type/wattage were used to light a trapping site per night. The type of bulb used per site was rotated every night to avoid locational effect. Each type of bulb was used twice at a site, totalling to six effective trapping nights during the season, depending on occurrence of swarming.

The experiments were overlaid with existing setups of commercial trappers which consisted of 16 to 20 traditional drums of 150 litres capacity. The drums were arranged in a "U" shape to allow entry from the open end. The drums were suspended on wooden frames made of Eucalyptus poles, 0.6 m from the ground. Six traditional drums were randomly selected from each site as experimental units, of which three were used as controls and the other three were replaced with modified *R. differens* collection drums (treatments). One iron sheet was placed in each drum at about 75^0 to the inner vertical plane and tied to the eucalyptus pole to prevent it from falling. At least three quarters of the length of the iron sheet was outside the drums, both control and treatment drums were labelled as LD1 to LD3 and MD1 to MD3, respectively (Figure 3.2). Three bulbs connected to the power source per site were hanged above the drums on Eucalyptus poles (6 m high).

3.3. Experimental design: Second season

The trial was carried out during the swarming season from November to December, 2019. Owing to observations that catches of *R. differens* were influenced by wattage of LED lights with both 100 W and 200 W bulbs catching significantly fewer *R. differens* than 400 W mercury bulbs (see results), the experimental design used in the first season was modified by adding 400 W LED bulbs (Cob, GS light, YAYE lighting company, Zhongshan, China), increasing the number of types of bulbs from three to four (LED: 100 W, 200 W and 400 W; and mercury: 400 W). The trapping duration was extended from six to eight days to allow each bulb the chance to be used twice per site. Other procedures in the second season were like those in the first season. Trials were carried out for a total of 14 nights spread out over the two swarming seasons. The limited number of trapping nights was due to unpredictability of the swarms which resulted in some nights recording no swarms. A total of 7 nights in the two swarming seasons were excluded from the total number of nights considered for the study because no catches were obtained during those nights. The trapping duration was also constrained by the high cost of site fees (each trapper was paid UGX. 200,000 as site fees per effective trapping night). The budget for the study could only facilitate 14 effective trapping nights.

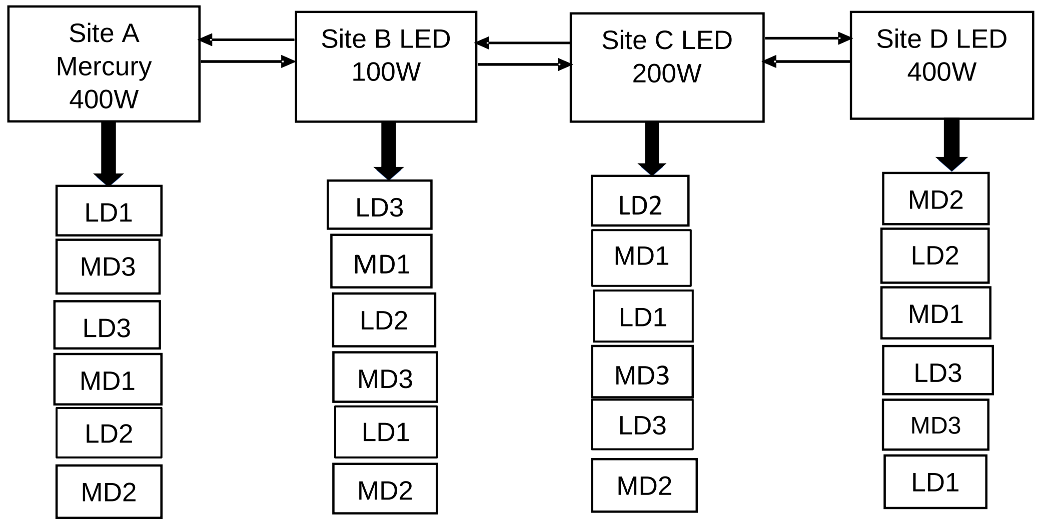

Figure 3.2: Randomized Complete Block Design (RCBD) for *R. differens* trapping experiments

3.4. Data collection

3.4.1. Evaluation of modified drums and LED bulbs

Trapping was done for 9 hrs each night from 8.00 PM to 5.00 AM, East African Time, as is traditionally practiced by commercial trappers. After the trapping night, iron sheets were removed from all the drums and the drum-tops were covered with bags. The catch in each traditional drum was poured into separate polythene bags. For the modified drums, trapped *R. differens* and other big non-target insect species remained in the first and second compartments. Therefore, the doors for each compartment were opened one at a time and the catch was picked by hand and put in separate polythene bags. Fresh weight of *R. differens* caught in each drum and compartment was recorded.

The catches of *R. differens* from each traditional drum and the compartments of the modified drums (upper and middle) were separately sorted manually to remove non-target species. Non-target insect species that were filtered through to the lower compartments of the modified drums were manually collected while wearing food-grade gloves. Non-target insects were placed in labelled 250 ml plastic bottles containing ethyl acetate in cotton wool to kill them (Silva et al., 2015). For each non-target lepidopteran morpho-species, five individuals were pinned for morphological identification and deposited in the museum at the department of Zoology Entomology and Fisheries Sciences, Makerere University. For non-lepidopterans, five individuals were wet preserved by putting them in 250 ml plastic bottles containing 100 ml of 95% ethanol

(Duehl et al., 2011). The remaining lepidopteran samples were kept in labelled paper envelops while the non-lepidopterans were put in 400 ml plastic bottles containing 300 ml of 95% ethanol to keep them intact (Duehl et al., 2011). Samples were identified at the museum at the Department of Zoology, Entomology and Fisheries Sciences, Makerere University using identification keys described by Klimaszewski and Watt, (1997). Lepidopterans were identified using keys described by Jagbir and Mudasir, (2013), www.African moth. com, www.Afromoth.net and Timm et al., (2007). After morphological identification of the non-target species, the number of individuals per species was recorded.

3.4.2. Cost benefit analysis

The cost effectiveness of the improved and traditional trapping techniques were determined according to the protocol described by Paine et al., (2015). All the costs and benefits associated with using the traditional technique of trapping *R. differens* were gathered through direct interviews. Out of the fifty (50) commercial trappers in Nyendo town according to the association of grasshopper trappers ("Basenene"), thirty individuals were considered as an appropriate representative sample (Paine et al., 2015) and these were selected randomly. A pretested questionnaire was then used to obtain detailed information on all the operating costs and capital expenditures as well as the returns from trapping *R. differens* using the traditional technique. The current market prices for the materials used in the traditional trapping technique were also determined to confirm the prices given by the respondents. All the operating costs, capital expenditures and the returns of the improved trapping method were captured basing on the current market prices (Popp, 2011). The non-monetary costs for example family labor and benefits like harvesting clean *R. differens* were converted to monetary value by using the concept of willingness to pay as described by Engeman et al., (2003).

The cost of electricity for both improved and traditional trapping technique was determined by measuring electricity consumption of LED and mercury bulbs using Actaris electricity meters of 2000 kWh capacity (Actaris, Itron, London, UK), as described in Chapter 6, section 6.3.2.1

3.5. Data analyses

Catches of *R. differens* for each season were subjected to two-way Analysis of variance (ANOVA) to determine the effect of collection drum types and light sources on mean weights of *R. differens*. Mean kilowatts of electricity consumed by the LED and mercury bulbs were compared using one-way ANOVA. Mean weights of *R. differens* caught in the upper and middle compartments of the modified drums were compared using a two-sample t-test. Total counts of non-target species caught with *R. differens* were subjected to generalized linear models (GLMs) with Poisson distribution error and logit link, to determine effect of drum type, compartment and light source on the catches (Zuur et al., 2009). Counts of each morpho-species caught with *R. differens* were also subjected to GLMs with Poisson distribution error and logit link, to determine the effect of drum type and light source on the catches. All the GLMs had dispersion parameters which were approximately 1, which confirmed their suitability for the analyses. For non-target morpho-species which were recorded in only two compartments of the modified drums, mean counts were compared using Chi-squared (χ^2) tests. However, no statistical analysis was carried out on counts of non-target insects which were recorded only in one compartment of the modified drum; instead, means and standard errors of these counts were computed. Where necessary, Tukey's multiple comparisons were used for mean separation. All analyses were carried out in R-statistical computer software version 3.5.1 (R Development Core Team, 2018) at $\alpha = 0.05$.

The cost-benefit analysis was conducted using discounting measures of investment worth including net present value (NPV), benefit-cost ratio (BCR) and a non-discounting measure, the payback period.

CHAPTER FOUR: EFFECT OF DRUM DESIGN AND LIGHT SOURCE ON CATCHES OF *Ruspolia differens*

4.1. Abstract

Trapping of *R. differens* has been traditionally done using traditional light traps for a long period of time. In this study, the performance of modified collection drums and Light Emitting Diode (LED) bulbs for trapping *R. differens* was evaluated. Trials were carried out at four trapping sites in Nyendo town, Masaka district, central Uganda, for a total of 14 nights during April-May and November-December swarming seasons in 2019. Collection drums were modified by dividing each drum into three compartments to filter off non-target insects from *R. differens* and a funnel was fitted on top to allow easy falling of grasshoppers into the drums and to reduce escape. Three different wattages of LED bulbs (100 W, 200 Wand 400 W) were tested alongside 400 W mercury bulbs. Data was collected from three modified drums and three traditional drums for a total of fourteen days, by weighing of grasshoppers caught from each drum at the end of each trapping night. Results showed that modified drums collected a comparable quantity of *R. differens* as the traditional drums; 165.21±8.44 g and 172.35±8.69 g from the modified and traditional drums, respectively but without using contaminants like waste cooking oil, cassava flour and water. LED bulbs of 400 W trapped a mean weight of 211.48±8.78 g of *R. differens* which was not statistically different from 226.92±10.06 g trapped using mercury bulbs of the same wattage. Modified drums and LED 400 W bulbs are recommended for trapping *R. differens* in order to reduce contamination from materials like cassava flour, waste cooking oil, water and reduce the effects of mercury to the trappers and the environment.

4.2. Introduction

The human population is rapidly increasing worldwide and there is expected increase in meat consumption as a source of protein. By 2030, per capita meat consumption in high income countries could increase by 9%, while in developing countries the increase could be 50% when compared to per capita consumption in 2000 (Paul et al., 2016). Today, insects are increasingly being viewed as an alternative protein source for human consumption and animal feeds. Indeed, in many regions around the globe, edible insects have long played a vital role in satisfying human nutritional requirements (Paul et al., 2016; Banjo and Songonuga, 2006). Traditionally, more than 2000 insect species are consumed worldwide at different stages of their life cycle. In many African countries, a number of native edible insect species are harvested from the wild by different communities (Van-Huis et al., 2013). The most commonly consumed insect species belong to the order Coleoptera (beetles) with 31% of all species consumed, followed by the Lepidoptera (caterpillars) (18%), the Hymenoptera (bees, ants and wasps) (14%) and the Orthoptera (grasshoppers and crickets) (13%), ((Paul et al., 2016; Jongema, 2015). In Uganda, insect species commonly used as food include; long-horned grasshoppers (*Ruspolia differens*), palm weevils (*Rhynchophorus phoenicis*) larvae and termites (*Macrotermes* spp), (Okia et al., 2017). *Ruspolia differens* and *Macrotermes* spp swarm seasonally and people trap them using traditional traps during the swarming seasons.

Trapping of *R. differens* has become a lucrative business in central, western and some districts in West Nile, mid-west and eastern parts of Uganda during the swarming seasons. However, the activity remains traditionally done using traditional light traps. In Tanzania, 400 W mercury bulbs, metallic drums and 60 litre plastic buckets are used with a funnel on top in order to reduce escape of grasshoppers because the buckets are short (Mmari et al., 2017). In Uganda, traps consist of metallic drums and mercury bulbs of 400 – 1000 W (Okia et al., 2017). The drums are open at the top and this allows easy escape of trapped *R. differens*.

The quantity of *R. differens* caught is most likely to be affected by the design of the collection containers and the light source. Okia et al. (2017), reported that commercial trappers sprinkle cassava flour, water and old used cooking oil into the drums in order to prevent grasshoppers from escaping. This is an indicator that the design of the drum does not effectively retain the trapped grasshoppers. In this study, a modified drum was designed as described in Chapter One section 1.1

with an intention of increasing the retention of trapped grasshoppers and reducing the number of non-target insects as a pre-requisite to improve on the trapping technique of *R. differens*. The light source is also an important factor in trapping *R. differens* but the mercury bulbs currently used when poorly disposed, they release mercury that causes irritation of eyes and accumulate in the food chain, hence affecting the health of people and other organisms. Alternatives to these mercury bulbs are the LED bulbs because they are energy efficient, durable and less hazardous to humans and the environment (Lim et al., 2012). It was therefore, important to test the effectiveness of the modified drums and LED bulbs in trapping *R. differens.* In this study, the effectiveness of the modified drums in retaining *R. differens* and avoiding contamination from waste cooking oil, water and cassava flour that are traditionally used to retain the catch in the drums was evaluated. The effectiveness of LED bulbs in attracting *R. differens* was also evaluated.

4.3. Materials and methods

This study was carried out at four trapping sites in Nyendo town, Masaka district, central Uganda. The details of the study area are described in Chapter Three, section 3.1.

4.3.1. Data collection

Data were collected for a total of 14 nights in two swarming seasons from experiments set at four trapping sites as described in Chapter Three, sections; 3.2 and 3.3.1. During each trapping night, the experiments in all the four sites were monitored and observations made from each site were recorded. At the end of each trapping night, the catch from each traditional drum was poured in polythene bags. For the modified drums, the catch from the middle and upper compartments were removed through the doors on each compartment and put in polythene bags separately. These were then weighed using Taylor digital kitchen scale of 0.01 g (Taylor precision, London, UK) the weights were recorded indicating the drum type, compartment, bulb type and wattage.

4.3.2. Data analysis

To compare the mean weights of *R. differens* caught from the modified and traditional collection drums; and across light sources: mercury bulbs (400 W) and LED bulbs (100 W, 200 W and 400 W), a two-way analysis of variance was conducted. Tukey's multiple comparison ($\alpha = 0.05$) was used for post hoc separation of mean weights of *R. differens*. A two-sample t-test was conducted to compare the mean weights of *R. differens* caught in the upper and middle compartments of the modified drums.

4.4. Results

4.4.1. Effect of collection drum design and light source on the catches of *R. differens*

The mean weights of *R. differens* caught in modified drums in the first season (120.21 ± 5.89 g) and second season (165.21 ± 8.44 g) were not significantly different from the mean weights of the catches in the traditional drums ($F_{1, 53} = 0.20$, $P = 0.652$ and $F_{1, 104.27} = 43.12$, $P = 0.44$ in the first (116.37 ± 6.6 g) and second (172.35 ± 8.69 g) seasons, respectively) (Figure 4.1). In the first season, there was a significant effect of source of light on catches of *R. differens* ($F_{2, 93.82} = 6.37$, $P = 0.002$). The mean weight of *R. differens* caught per drum lit with 400 W mercury bulb (138.56 ± 7.83 g) was significantly higher than the mean weights caught using 100 W (96.81 ± 8.89 g) and 200 W (139.64 ± 9.89 g) LED bulbs (Figure 4.2). However, the catches in the two types of LED bulbs were not significantly different. Similarly, the type of bulb had a significant effect on catches of *R. differens* in the second season ($F_{3, 104.27} = 42.15$, $P = 0.0001$). The weight of *R. differens* caught using LED 400 W lit drums per night (211.48 ± 8.78 g) was not significantly different from catches (226.92±10.06 g) by mercury 400 W bulbs. However, these catches were significantly higher than the weights of *R. differens* caught using LED 200 W and 100 W bulbs.

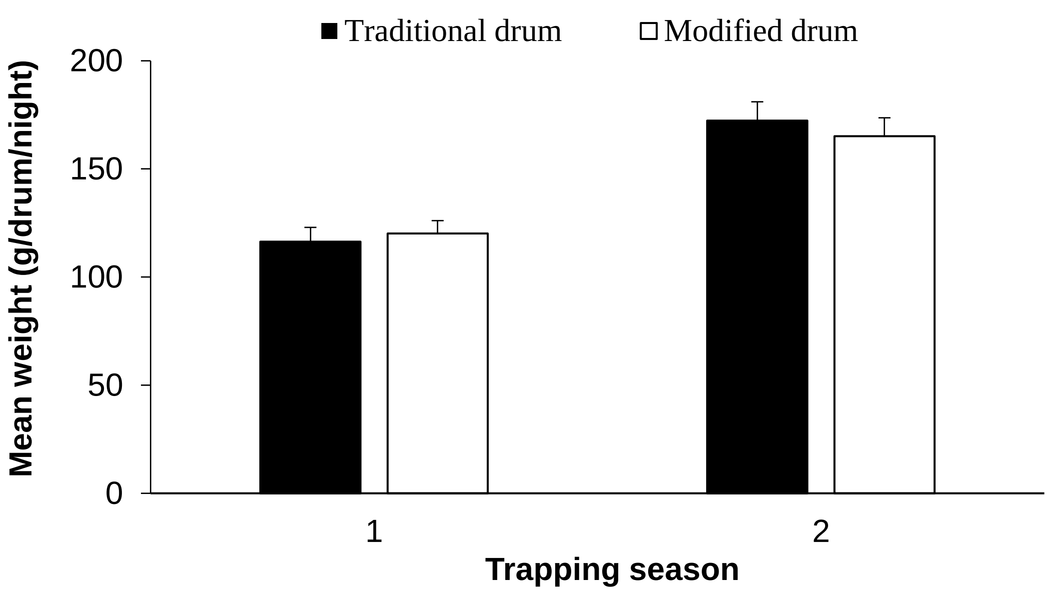

Figure 4.1: Mean (±SE) weight of *R. differens* caught in the modified and traditional drums per season in 2019. Error bars represent standard errors of the mean

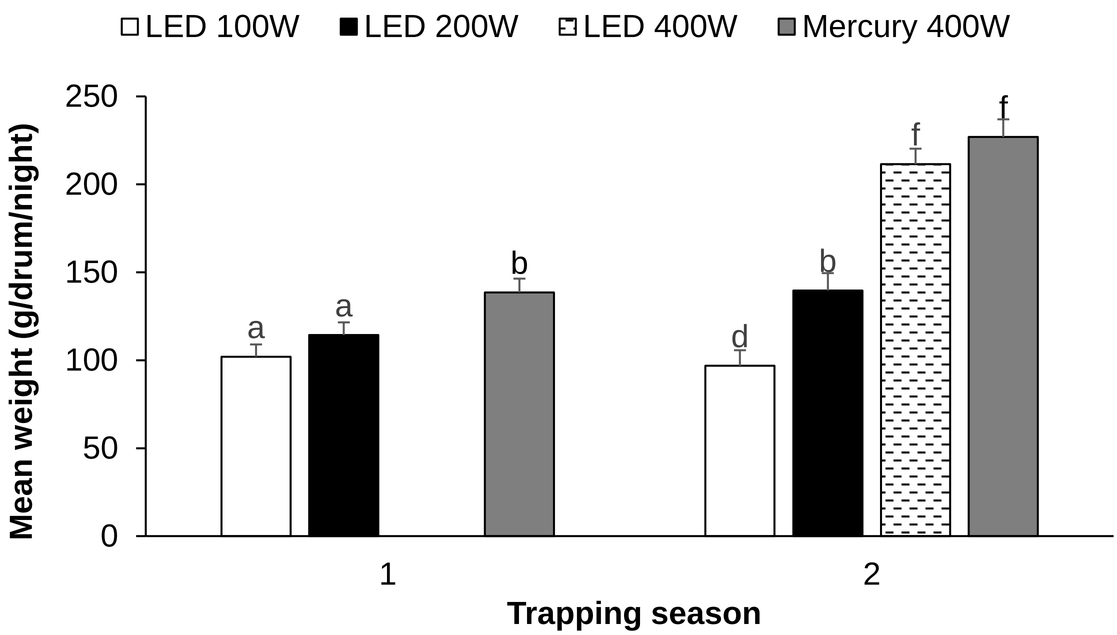

Figure 4.2: Mean (±SE) weight of *R. differens* caught using different types of bulbs per season in 2019. Bars within a season with the same letters are not significantly different (α = 0.05). Error bars represent standard errors of the mean. 400 W LED bulbs were not tested in the first season

4.4.2. Efficiency of wire meshes in filtering *R. differens* to the middle compartment

The mean weights of *R. differens* caught in the upper compartment per night in the first season (42.95 ± 2.43 g) and the second season (128.84 ± 7.28 g) were significantly higher than those caught in the middle compartment (t = 11.89, d.f. = 190, P = 0.0001 and t = 11.99, d.f. = 194, P = 0.0001 in the first (12.51 ± 0.74 g) and second (37.55 ± 2.22 g) season, respectively) (Figure 4.4). There was no *R. differens* caught in the bottom compartment during both trapping seasons.

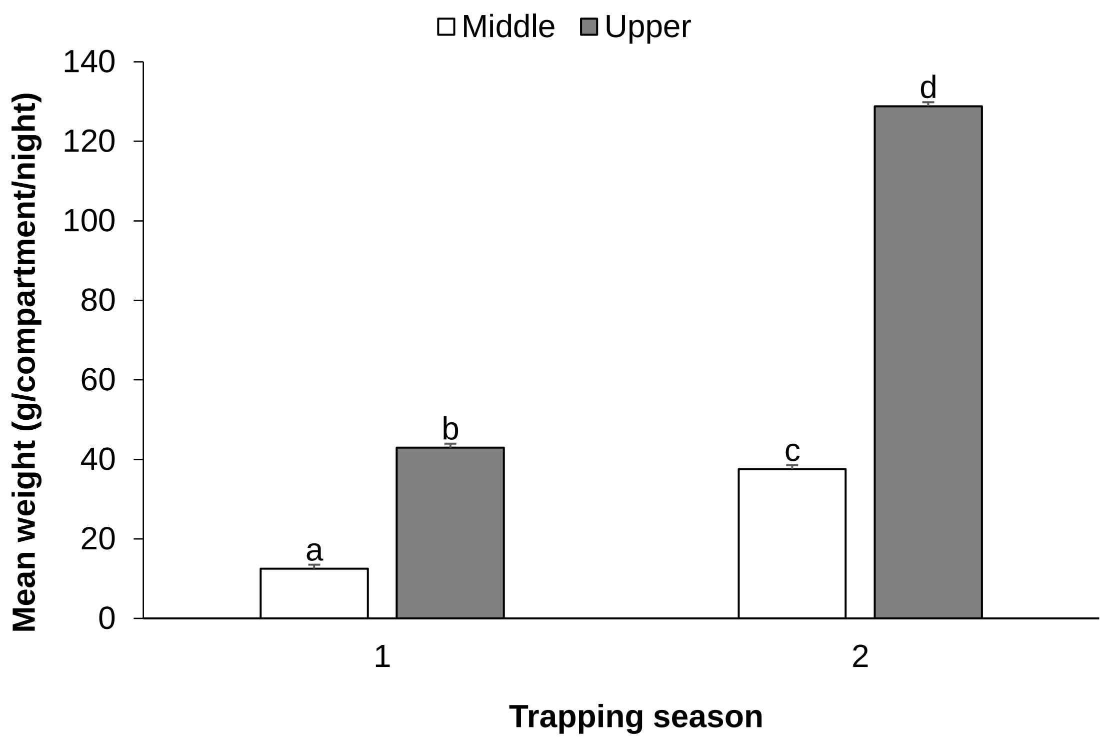

Figure 4.3: Mean (±SE) weight of *R. differens* caught in the middle and upper compartments of the modified drum per season in 2019. Bars within a season with the same letters are not significantly different (α = 0.05). Error bars represent standard errors of the mean

4.5. Discussion

4.5.1. Effect of collection drum design and light source on the weight of grasshoppers caught

Results from this study indicated that the mean weights of *R. differens* caught in the modified drums and traditional drums were comparable. This suggests that the funnel in the modified drum was as effective in retaining *R. differens* catches as the materials (water, cassava flour and old used cooking oil) used by traditional trappers. The finding suggests that adoption of the modified drum in trapping *R. differens* would help in avoiding the traditional practice of applying materials like water, cassava flour and waste cooking oil on the drums. Importantly, this would improve on the quality of *R. differens* harvested and reduce the risk of carcinogenic diseases associated with waste cooking oil to consumers (Ganesan et al., 2017).

The mean weight of *R. differens* caught using LED bulbs increased with the increase in the wattage of the bulbs. This indicates that *R. differens* responds proportionately to light intensity. Insects exhibit two major phototactic behaviours which include attraction (positive phototaxis) and repulsion (negative phototaxis). However, these two responses are affected by the intensity and wavelength of the light and this varies among insect species (Shimonda and Honda, 2013). Lysakov et al., (2019), found blue LEDs of wavelength within 440-470 nm effective at trapping locusts. Therefore, the optimum intensity, wavelength and color of light for *R. differens* needs to be investigated. Importantly, the LED 400 W bulbs attracted the same quantity of *R. differens* as the traditionally used mercury 400 W bulbs. This first report of the effectiveness of LED bulbs in trapping *R. differens* corroborate the proposition by Silva et al., (2016) that LED bulbs could be useful for trapping other insect orders apart from mosquitoes. Price and Baker, (2016) also reported that LED bulbs can effectively attract nine insect orders which included; Ephemeroptera, Plecoptera, Trichoptera, Diptera, Coleoptera, Hemiptera, Hymenoptera, Orthoptera and Lepidoptera. But these were not classified to lower taxa. The use of LED bulbs is advantageous because, they do not release mercury hence they reduce the health effects of mercury to harvesters, neighbours and the environment (Lim et al., 2012).

4.5.2. Efficiency of wire meshes in filtering *R. differens* to the middle compartment

Ruspolia differens was not found in the bottom compartments of the modified drums, suggesting that a 3 x 3 mm wire mesh effectively prevented the grasshoppers from going through to the bottom. On the other hand, the mean weight of *R. differens* caught in the upper compartment was significantly higher than that in the middle compartment, contrary to the intention of retaining only non-target insects bigger than *R. differens* in the upper compartment. This may be a result of adhesive action of numerous hairs located on pulvilli found on the tarsi of *R. differens* (Matojo, 2017), that allowed a majority of them to hold onto the mesh, hence preventing them from going through to the middle compartment. It is also possible that *R. differens* that crossed to the middle compartment could revert back to the upper compartment in an attempt to fly off to the light, only to be intercepted by the funnel. However, retention of *R. differens* in the upper compartment predisposes them to escape because they can easily fly out through the funnel opening. Therefore, the top mesh was found inessential, which necessitates further improvement of the collection drum to separate non-target insects that are of the same size or bigger than *R. differens*.

4.6. Conclusion and recommendation

Modified drums and LED 400 W bulbs were found to be effective in trapping *R. differens* hence they can be used as alternative trapping techniques as a step to improve trapping of *R. differens*. However, the upper compartment in the modified drums was found to be unnecessary hence, it is recommended to be removed so that the efficiency of the modified drums is improved. Further studies evaluating *R. differens* collection drums should consider using numbers of *R. differens* instead of weights to evaluate the performance of the collection drums. This is because the catch comes with many non-target insects and materials used to retain the catch in the traditional drums also mix with *R. differens* hence increasing the weight of the catch from traditional drums.

CHARPTER FIVE: EFFECT OF COLLECTION DRUM DESIGN AND LIGHT SOURCE ON THE NUMBER OF NON-TARGET INSECTS CAUGHT WITH *Ruspolia differens*

5.1. Abstract

Insect traps normally attract several non-target species depending on the design of the trap and the attractant used. Traditional traps used for trapping *R. differens* also trap other non-target insects and these insects contaminate the trapped grasshoppers. This study evaluated the effect of the modified drums and LED bulbs (100 W, 200 W and 400 W) on the number of non-target insect species caught with *R. differens*. Experiments were set at four randomly selected trapping sites of commercial trappers in Nyendo town, Masaka district, central Uganda, for a total of 14 nights during April-May and November-December swarming seasons in 2019. All non-target species found in grasshoppers trapped per drum and those in the bottom compartment of the modified drums on each trapping night were removed by hand, counted and later identified. The findings show that *R. differens* caught from the modified drums contained significantly fewer non-target species which were smaller than grasshoppers. Interestingly 85% of the Nairobi flies (*Paederus* sp) which is the most hazardous non-target species was filtered out of the grasshoppers hence they were cleaner and safer compared to those caught from traditional drums. The number of non-target species caught using LED 100 W, 200 W, 400 W and mercury 400 W bulbs were not significantly different. The bottom wire mesh was effective at filtering off non-target species smaller than *R. differens* to the bottom compartment. However, the upper wire mesh was not effective at filtering non-target species which were of the same size or bigger than *R. differens*. Therefore, this study recommends replacing the upper mesh with a smaller wire mesh that can allow *R. differens* to go through but holds bigger non-target insects in order to reduce contamination by non-target insects that are bigger than *R. differens*.

5.2. Introduction

Traps designed for specific insect species or insect groups may use combinations of cues to lure the target insect and exploit aspects of the insect's behavior in order to facilitate movement of insects into the trap (Epsky et al., 2008). Most insect traps normally attract several non-target species depending on the design of the trap, the attractant used and trap colour (Galdino and Raga, 2018). Pheromone traps are specific to insects of a particular group but sometimes non-target insects are found in these traps because some insects are attracted to the colour of the trap. Clare et al., (2014), found more non-target insects in white pheromone traps compared to green and red traps.

Baited traps also attract a number of non-targets. The bait put in a trap is a strong determinant of the non-target species attracted to the trap. Galdino and Raga, (2018), reported that McPhail traps baited with proteinaceous compounds and salts which were targeting fruit flies, trapped a number of insect orders which included; Hymenoptera, Hemiptera, Lepidoptera and Coleoptera. Light traps attract a number of non-target insects because many nocturnal insects are attracted to light (Epsky et al., 2008). Common insect orders caught in light traps include; Ephemeroptera, Plecoptera, Trichoptera, Diptera, Coleoptera, Hemiptera, Hymenoptera, Orthoptera and Lepidoptera (Price and Baker, 2016). However, the number of non-target individuals caught also depend on the habitat where the trap is placed. Traps deployed in forests and grasslands trap many non-target species (Clare et al., 2014).

Non-target species are unwanted in most insect traps because they negatively affect the efficiency of the trap depending on its design and purpose. In sticky base pheromone traps, presence of non-targets is a nuisance and requires more frequent changing of the sticky bases (Clare et al., 2014). Non-target species can contaminate traps intended to capture a specific insect species. According to Myers et al., (2009), contamination of pheromone traps by non-target species results into increased time for trap maintenance and increased costs associated with periodic replacement of soiled trap bottoms. Besides the problem of trap contamination, inordinate capture of non-targets in different traps is destructive for example capture of beneficial bees may reduce pollination or reduce populations of commercial honeybee colonies that are of significant economic importance (Myers et al., 2009). Capturing of non-targets also leads to reduction of insect populations which are ecologically important and some of these populations may be threatened in the habitats where they exist.

It is very important to design traps that can reduce or eliminate non-target insects. Depending on the design and the attractant used, traps can be sufficiently attractive to the species of interest while remaining unattractive to non-target species (Myers et al., 2009). Clare et al., (2014), recommended replacement of white colour in pheromone trap with green or red to reduce the number of non-targets because these colours are less attractive to non-target insects. Myers et al., (2009), also found yellow, red, orange or green less attractive to non-target insects. Galdino and Raga, (2018), recommended use of Lures that provide low release rates of ammonia in bait traps and specific light colors in light traps, in order to avoid non-target insects.

Traps used for trapping *R. differens* use light as an attractant and many non-target species are trapped with grasshoppers. This is because light traps are not specific to a particular insect species so they attract many nocturnal insect species (Duehl et al., 2011). The traditional drums used are also non selective because they are open at the top, the non-target insects contaminate trapped *R. differens* for example by secreting chemicals. The Nairobi fly (*Paederus sabaeus*) for example secrets pederin which causes dermatitis and temporary blindness (Iseroson and Walton, 2012). In an effort to improve the trapping technique of the long-horned grasshoppers, modified drums were designed to reduce the number of non-target insects trapped with grasshoppers by filtering them off. LED bulbs were explored as alternative light sources to the conventional mercury bulbs currently used by trappers.

5.3 Materials and methods

This study was carried out at four trapping sites in Nyendo town, Masaka district, central Uganda. The detailed description of the study area is provided in Chapter Three, section 3.1.

5.3.1. Data collection

Experiments were set as described in chapter Three section; 3.2. The catch from each type of drum per site was immediately spread on white sheets of paper one batch at a time and all the non-target insects were picked out by hands worn in plastic gloves. Each of the morphospecies found were counted, recorded and put in separate 250 ml plastic containers containing balls of cotton wool that had been soaked in ethyl acetate to kill them. The containers were labelled indicating the date, site, bulb type, drum type and the compartment from which the catch was collected. Non-target species from the bottom compartments were picked by hand through the doors and morphospecies counted before being placed in separate 250 ml plastic containers containing balls of cotton wool that had been soaked in ethyl acetate. Morphospecies were preserved and later identified as described in Chapter Three sections; 3.3.1.

5.3.2. Data analysis

To determine the effect of collection drum, compartment and light source on the total catches, data was subjected to generalized linear modelling with Poisson distribution error and logit link as described in chapter three section 3.4. The number of each species caught in the modified and traditional collection drums across the different light sources were also subjected to generalized linear modelling with Poisson distribution error and logit link, to determine the effect of collection drum and light source on catches of each species (Zuur et al., 2009). All models on counts of non-target morphospecies had dispersion parameters which were approximately 1, therefore, they were considered fit for the Poisson generalized linear model. The resulting mean numbers were separated using Tukey's test ($\alpha = 0.05$). For non-target insects which occurred in two compartments of the modified drums, Chi-squared (χ^2) test was conducted to compare their mean number between the compartments. For non-target insects which occurred in only one of the collection drums compartments, no statistical analysis was applied but the mean counts and standard errors of the means were computed.

5.4. Results

5.4.1. Effect of drum design and light source on the number of non-target insect species found with trapped *R. differens*

The findings show that lepidopterans were the most common non-target insects trapped with *R. differens*. A total of nine non-target species were identified and these included five lepidopterans: *Acherontia* sp. Linnaeus (Lepidoptera: Sphingidae), *Achaea* sp. (Walker) (Lepidoptera: Erebidae), *Haritalodes* sp. Fabricius (Lepidoptera: Crambidae), *Amerila* sp. (Hauser and Boppre) (Lepidoptera: Erebidae) and *Mythimna* sp. (Walker) (Lepidoptera: Noctuidae); three coleopterans: *Paederus* sp., *Cybister* sp. (Olivier) (Coleoptera: Dytiscidae), *Heteronychus* sp. Fabricius (Coleoptera: Scarabaeidae) and one hemipteran: *Lethocerus* sp. Linnaeus (Hemiptera: Belostomatidae) (Figure 5.1). The total number of non-target insect species collected with *R. differens* from the modified *R. differens* collection drums was significantly lower than total counts of non-target species in *R. differens* from traditional drums (Table 5.1; Figure 5.2). The number of *Achaea* sp., *Acherontia* sp., *Amerila* sp., *Cybister* sp., *Haritalodes* sp., *Heteronychus* sp., *Mythimna* sp., and *Paederus* sp. collected with *R. differens* from modified drums was significantly lower than those collected with *R. differens* from traditional drums in the first and second seasons. However, the number of *Lethocerus* sp. was significantly lower in the second season but not significant in the first season (Table 5.1).

There were no significant effects of light intensity on the total number of non-target species collected with *R. differens* (Table 5.1; Figure 5.3). Similarly, there was no effect of light source on the number of individual non-target species collected with *R. differens* in the first and second seasons.

Acherontia sp.

Achaea sp.

Amerila sp.

Mythimna sp.

Haritalodes sp.

Paederus sp.

Cybister sp.

Heteronychus sp.

Lethocerus sp.

Figure 5.1: Non-target species trapped with *R. differens*

Table 5.1. Summary of statistical parameters from generalised linear models for the effect of drum design and light source on the number of non-target species collected with *Ruspolia differens*

Identity	Season 1			Season 2		
	χ^2	df	P	χ^2	df	P
Drum design						
Total non-targets	10.7	1	0.001	747.6	1	0.001
Achaea sp	52.9	1	< 0.001	141.8	1	< 0.001
Acherontia sp	0.3	1	0.042	10.4	1	0.001
Amerila sp	66.1	1	< 0.001	183.7	1	< 0.001
Cybister sp	8.7	1	0.003	0.6	1	0.043
Haritalodes sp	4.1	1	0.043	7.2	1	0.007
Heteronychus sp	0.4	1	0.003	0.9	1	0.034
Lethocerus sp	0.8	1	0.245	0.3	1	0.006
Mythimna sp	47.8	1	< 0.001	124.5	1	< 0.001
Paederus sp	186.7	1	< 0.001	1145.7	1	< 0.001
Light source						
Total non-targets	1.7	2	0.419	3.4	3	0.339
Achaea sp	0.6	2	0.743	0.7	3	0.884
Acherontia sp	0.3	2	0.852	0.9	3	0.819
Amerila sp	0.3	2	0.863	2.3	3	0.518
Cybister sp	0.3	2	0.843	3.3	3	0.349
Haritalodes sp	0.4	2	0.817	0.5	3	0.923
Heteronychus sp	0.5	2	0.786	1.3	3	0.733
Lethocerus sp	1.2	2	0.559	1.2	3	0.749
Mythimna sp	0.2	2	0.923	0.1	3	0.994
Paederus sp	0.5	2	0.764	1.1	3	0.781

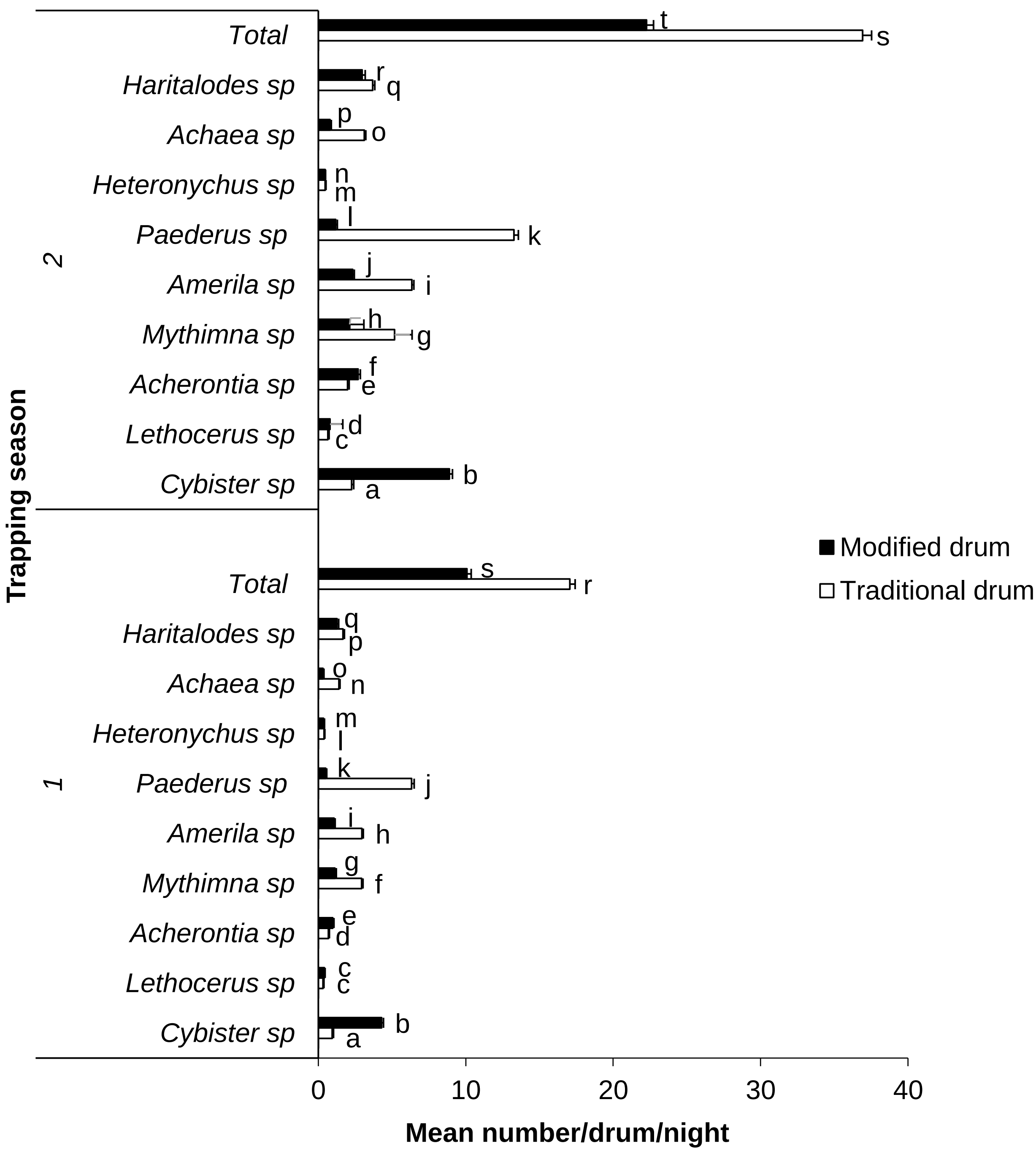

Figure 5.2: Mean (±SE) number of non-target species found with *R. differens* caught from the modified and traditional drums per season in 2019. Bars within a season with the same letters are not significantly different (α = 0.05). Error bars represent standard errors of the mean

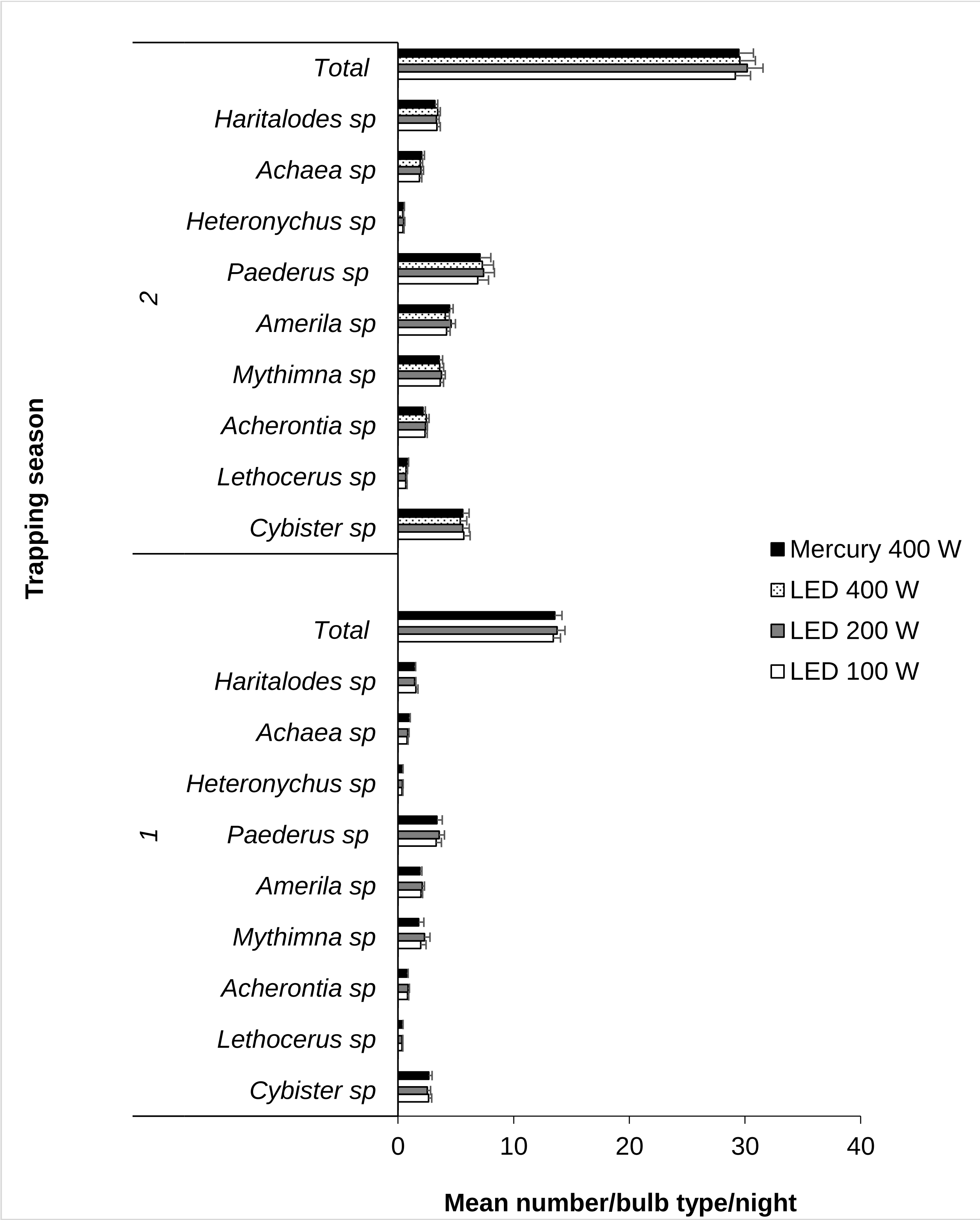

Figure 5.3: Mean (±SE) number of non-target species collected with *R. differens* using different types of bulbs per season in 2019. Error bars represent standard errors of the mean. LED 400 W was not tested in the first season

5.4.2. Efficiency of wire meshes in filtering off non-target insect species from *R. differens*

The total mean number of non-target insects caught in the upper, middle and bottom compartments per night was significantly different (χ^2 = 1020.3, df = 2, P = 0.0001 and χ^2 = 2345.4, df = 2, P = 0.0001 in the first and second season, respectively) (Table 5.2). However, some non-target species occurred in one compartment while others occurred in two compartments of the modified drums. Specifically, *Lethocerus* sp., *Acherontia* sp. were caught in the upper compartment only. *Mythimna* sp. and *Amerila* sp. were found in the middle compartment only while *Heteronychus* sp. was only caught in the bottom compartment. *Cybister* sp. was found in the upper and middle compartments while *Achaea* sp., *Haritalodes* sp. and *Paederus* sp. were found in the middle and bottom compartments. The mean number of *Cybister* sp. caught in the middle compartment was significantly higher than those in the upper compartment (χ^2 = 110.41, df = 1, P = 0.0001 and χ^2 = 136.86, df = 1, P = 0.0001 in the first and second season, respectively). The mean number of *Achaea* sp., *Haritalodes* sp. and *Paederus* sp. caught in the bottom compartment in the first season was significantly higher than that caught from the middle compartment (χ^2 = 113.09, df = 1, P = 0.001), (χ^2 = 40.83, df = 1, P = 0.0001) and (χ^2 = 111.63, df = 1, P = 0.0001), respectively. Similarly the mean number of *Achaea* sp., *Haritalodes* sp. and *Paederus* sp. caught in the bottom compartment in the second season was significantly higher than that caught from the middle compartment (χ^2 = 143.94, df = 1, P = 0.0001), (χ^2 = 145.95, df = 1, P = 0.001) and (χ^2 = 142.32, df = 1, P = 0.0001), respectively.

Table 5.2: Mean number of non-target species caught in the different compartments of the modified drum per season in 2019. Values on the same row within a season with the same letters are not significantly different (α = 0.05)

Species	**Season 1**			**Season 2**		
	Mean No. per compartment			**Mean No. per compartment**		
	Upper	**Middle**	**Bottom**	**Upper**	**Middle**	**Bottom**
Acherontia sp.	2.7±0.2			5.5±0.3		
Mythimna sp.		2.3±0.1			4.6±0.2	
Amerila sp.		2.4±0.1			5.1±0.2	
Achaea sp.		$0.9±0.1^{a}$	$6.4±0.2^{b}$		$2.2±0.2^{l}$	$12.3±0.3^{m}$
Haritalodes sp.		$3.2±0.2^{c}$	$5.5±0.2^{d}$		$6.3±0.4^{n}$	$10.1±0.4^{o}$
Paederus sp.		$1.2±0.1^{e}$	$10.5±0.3^{f}$		$2.8±0.2^{p}$	$21.2±0.6^{q}$
Cybister sp.	$0.9±0.1^{g}$	$8.6±0.2^{h}$		$2.1±0.2^{r}$	$10.6±0.4^{s}$	
Heteronychus sp.			0.5±0.1			1.4±0.1
Lethocerus sp.	0.9±0.1			2.1±0.2		
Total	$\mathbf{4.7±0.3^{i}}$	$\mathbf{18.7±0.4^{j}}$	$\mathbf{22.9±0.5^{k}}$	$\mathbf{9.7±0.5^{t}}$	$\mathbf{31.7±0.7^{u}}$	$\mathbf{44.9±0.6^{v}}$

5.5. Discussion

5.5.1. Effect of drum design and light source on the number of non-target insect species

Ruspolia differens caught in modified drums contained less non-target insects compared to those from traditional drums, suggesting that contamination by non-targets was reduced. This could have resulted because *R. differens* was only collected from the upper and middle compartments of the drums which were free from smaller non-target insects that were efficiently filtered to the bottom. Interestingly, about 85% of *Paederus* sp. which secretes pederin that causes irritation of eyes and dermatitis to both trappers and processors of *R. differens* (Iseroson and Walton, 2012) was collected in the bottom compartment. This was a significant improvement in the safety to commercial trappers, processors and consumers of *R. differens* from this hazardous insect. Several cases of dermatitis caused by *Paederus* sp. in humans have been reported by Beaulieu and Irish, (2016), Gibbs, (2015) and Cressey et al., (2013).

Five out of nine non-target species trapped with *R. differens* were lepidopterans. This is consistent with previous reports that most nocturnal insects belong to the order Lepidoptera (Price and Baker, 2016; Nowinszky., 2014). This result concurs with the report by Ramamurthy et al., (2010) that lepidopterans account for most insects caught in different types of light traps. A majority of the lepidopterans trapped were *Achaea* sp. and *Haritalodes* sp. and these were found in the bottom compartments because they were smaller than *R. differens*. This means *R. differens* caught in modified drums contained fewer lepidopterans compared to those from traditional drums. The health effects of some of these non-target insects to humans is not known. However, if they are not eliminated from *R. differens*, the processors spend a lot of time and more energy to sort them out. The scales from lepidopterans contaminate *R. differens,* hence requiring thorough washing which takes a lot of water and time. Non-target insects that were trapped are food for birds and predatory insects and lepidopterans especially the Noctuids are pollinators (Goldstein, 2017). Therefore, filtering some of them to the bottom compartments of modified drums where they were not mixed with *R. differens* could allow trappers to easily release them back to the wild. This would contribute to conservation of these species, unlike in the traditional drums where they end-up being packed in sacks together with *R. differens*.

The total numbers of non-target species caught with *R. differens* using LED and mercury bulbs were not significantly different, indicating that the numbers of these non-target insects were not influenced by the intensity and type of light produced by the bulbs. This finding is consistent with

Duehl et al., (2011) who reported that most nocturnal insects are attracted to light irrespective of its intensity and type. Therefore, efforts need to be focused on improving the collection drums to reduce the number of non-target insects trapped with *R. differens*.

5.5.2. Efficiency of wire meshes in filtering off non-target insect species from *R. differens*

The upper and middle compartments contained less non-target insects compared to the bottom compartment. This is because most of the non-target insects were smaller than *R. differens*, so they were filtered out by the wire meshes. Since *R. differens* was only collected from the upper and middle compartments which had less non-targets than the bottom compartment, *R. differens* collected from modified drums were less contaminated with non-target insects compared to those collected from traditional drums. Non-target species were relatively effectively separated to the different compartments according to their sizes. However, non-target species that were bigger than *R. differens* (*Lethocerus* sp., *Acherontia* sp. and *Cybister* sp.) were not filtered out of the catch as desired. The existence of insects of the same species in two compartments was due to variation in the sizes of these insects and their ability to move to the different compartments. For example, *Achaea* sp., *Haritalodes* sp. and *Paederus* sp., that were filtered into the bottom compartment were able to move into the middle compartment and contaminate *R. differens*. Therefore, there is need for further improvement of the collection drum to separate non-target insects that are of the same size or bigger than *R. differens* and to prevent non-targets filtered into the bottom compartment from moving into the middle compartment.

5.6. Conclusion and recommendation

The modified drum was effective at filtering out most non-target species (*Heteronychus* sp., *Achaea* sp., *Haritalodes* sp. and *Paederus* sp.) from the grasshoppers. The Nairobi fly which is one of the most hazardous non-target insects was considerably reduced in harvested grasshoppers. Therefore, grasshoppers harvested using modified drums contained less Nairobi flies hence they were safer than those trapped using traditional drums. LED and mercury bulbs did not show any difference in the number of non-target species found with trapped grasshoppers. This study, recommends replacing the upper mesh with a smaller wire mesh that can hold big non-target insects and allows *R. differens* to go through in order to reduce the number of big non-target insect species (*Lethocerus* sp., *Acherontia* sp. and *Cybister* sp.) trapped with grasshoppers.

CHAPTER SIX: COST-BENEFIT ANALYSIS OF MODIFIED AND TRADITIONAL ***Ruspolia differens*** TRAPS

6.1. Abstract

The traditional trapping technique of *R. differens* was improved by fitting a funnel to the collection drums and dividing the drums into three compartments to increase retention of the catch and filter non-target species from *R. differens*. Mercury bulbs were replaced by LED bulbs to reduce the effect of mercury and increase energy efficiency. The improvements made increased retention of *R. differens* without using contaminants like waste cooking oil, reduced contamination from non-target species and reduced on the consumption of electricity. Adoption of the improved technique of trapping *R. differens* requires a cost-benefit analysis of the modified (LED bulbs and modified drums) compared to the traditional (mercury bulbs and traditional drums) techniques. A pre-tested questionnaire was used to collect data on the revenue, capital expenditures and operational costs of the traditional technique from 30 commercial trappers. The costs and revenue from the improved technique were also estimated. Electricity consumed by LED 400 W bulbs was half that consumed by the traditionally used mercury bulbs. The operating costs of the improved trapping technique were lower than those of the traditional technique, while the capital expenditures were higher than those of the traditional technique. The improved technique was more profitable than the traditional technique but it takes a longer time to pay back the capital invested. This study recommends use of the improved technique as an alternative for the traditional technique in order to improve the trapping business. However, there is need for further studies to develop low cost materials (drums and LED bulbs) used in the improved technique in order to increase the profitability of the trapping business.

6.2. Introduction

In many African countries, several local edible insect species are harvested from the wild by different communities using traditionally designed traps (Van-Huis et al., 2013). Trapping is done using different trap designs depending on the characteristics of the particular insect species especially the behaviour (Green et al., 2014). Traps usually consist of a collecting container which can be a bucket, drum or any other material that can collect the trapped insects and an attractant such as light. The cost and durability of these materials determine the cost effectiveness of a particular trapping method.

In Uganda, *R. differens* is harvested using traditional light traps composed of collection drums, iron sheets, electric wire, mercury bulbs and other materials like waste cooking oil, water and cassava flour (Okia et al., 2017). Some materials for example collection drums used to trap *R. differens* are locally available and cheap, hence, reducing the investment cost of the trapping method and making it cost effective. However, the cost effectiveness of the method is also influenced by the durability of the materials used and the variable costs involved. The collection drums and mercury bulbs traditionally used to trap *R. differens* are short-lived, hence require regular replacement which increases the investment costs. Waste cooking oil, cassava flour and water used to retain *R. differens* in the traditional collection drums and labor costs for daily application of these materials in the drums increase variable costs of the traditional trapping method. Electricity consumption of mercury bulbs is reportedly high (Bibha and Ranjana 2015) and this leads to high electricity bills. Lyatuu, (2019), reported that Umeme Limited (the largest electricity distributor in Uganda) charges US $ 94.97 per 400 W mercury bulb per season from trappers of *R. differens*. Therefore, a detailed cost-benefit analysis needs to be done to appropriately determine the cost effectiveness of the harvesting method.

This study aimed at improving the traditional trapping technique of *R. differens* through; (i) modifying the collection drums by fitting a funnel and dividing the drum into three compartments using wire meshes and (ii) replacing mercury bulbs with energy saving LED bulbs (Chapter one, section 1.1). The modified drums and LED 400W bulbs were found to be as effective in trapping *R. differens* as the traditional drums and mercury 400W bulbs, hence recommended for adoption (Chapter four, section 4.5.1; Chapter five, section 5.5.1). However, when developing a new technology, it is very important to determine its cost effectiveness and compare it with the existing technology because the cost is a major factor that determines its adoption (Katungi et al., 2011). In addition, trapping of *R. differens* has been commercialized in the central and western parts of Uganda. Agea et al., (2008) reported that trapping of *R. differens* is a profitable venture but there is no detailed information indicating the actual investments and returns from the business. Therefore, in this study, a cost-benefit analysis of trapping *R. differens* using the improved technique (modified drums and 400W LED bulbs) and using the traditional technique was carried out. The profitability of the modified and traditional technique was evaluated.

6.3. Materials and methods

6.3.1. Study site

The study was carried out in Nyendo town, Masaka district, central Uganda. The details of the study area are described in Chapter Three, section 3.1.

6.3.2. Data collection

6.3.2.1. Determining electricity consumption of LED and mercury bulbs

The amount of electricity consumed by LED (100 W, 200 W and 400W) and mercury 400 W light bulbs was measured using Actaris electricity meters of 2000 kWh capacity (Actaris, Itron, London, UK), which were connected to the bulbs at each trapping site. Electricity consumption in a night was determined by taking the readings before lights were turned on and just after switching them off, then subtracting the former from the latter. Electricity consumption per bulb per night was determined by dividing the electric consumption per night per site by the number of bulbs served by the meter.

6.3.2.2. Determining the costs and revenue of the improved and traditional trapping techniques

A pre-tested questionnaire (Appendix 2) was used to collect information from thirty respondents (commercial trappers of *R. differens*) through direct interviews as described in Chapter Three, section 3.3.2. For the traditional technique (traditional drums and mercury bulbs), all the operating costs which included labour for setting the traps and collecting the insects, electricity, maintenance and materials like cassava flour, water, old cooking oil that are used for retaining *R. differens* in the drums, were collected. The capital expenditures such as: drums, bulbs, iron sheets, eucalyptus poles, wires and chokes and the returns were also gathered from all the respondents. The operating costs, capital expenditures and the returns of the improved trapping technique (modified drums and LED bulbs) were captured basing on the current market prices.

6.3.3. Data analysis

Discounting measures of investment worth including net present value (NPV), benefit-cost ratio (BCR) and a non-discounting measure, the payback period, were used to analyze the economic viability of investing in the improved trapping technique compared to the traditional technique. The indictors of economic worth were calculated according to the following equations adapted from Faizal et al., (2019);

$$NPV = \sum_{t=1}^{n} \frac{(B_t - C_t)}{(1+r)^t} \quad \text{.........(i)}$$

Where C_t denotes cash outflows per year, t; B_t is cash inflows per year, t; n and r are number of years of the investment (1 to 5 years) and discount interest rate, respectively.

$$BCR = \frac{\sum_{t=1}^{t=n} \frac{B_t}{(1+r)^t}}{\sum_{t=1}^{t=n} \frac{C_t}{(1+r)^t}} \quad \text{.........(ii)}$$

$$Payback\ period = \frac{Cost\ of\ project\ or\ investment}{Annual\ cash\ flow} \quad \text{.........(iii)}$$

These calculations were based on the following assumptions:

i. Each trapper had twenty drums and three bulbs of each type (mercury and LED), as determined from personal observations. Revenues and costs were projected over a period of five years based on the items with the longest live span and items whose life spans were less than five years were reintroduced at the end of their lifespan.

ii. The total revenue/benefits were calculated based on thirty effective trapping nights in the season because although the traps were set up for an average of 60 consecutive nights in a season, swarms only occurred for an average of 30 nights in a season.

iii. The total operating costs were calculated based on sixty trapping nights in the season because traps were set up for an average of 60 consecutive nights in a season whether or not swarms of *R. differens* occurred in a given night.

iv. The investment period is based on the lifespan of 5 years of the drums, funnels, chokes and LED bulbs.

v. The maintenance cost of each technique is 10% of the total cost of drums for the respective technique, particularly because other items do require maintenance.

vi. The costs of bulbs, drums, electric wires, chokes, iron sheets, poles, labour, cassava flour and maintenance were assumed to be affected by inflation rate in the country with the current rate considered at 3.7%.

vii. The cost of water is estimated to remain constant for the first 3 years and increase by 3% in the fourth and fifth year based on the rare and low increment in the cost of a litre of water in the country.

viii. The cost of electricity is assumed to reduce by 1.2% in the five years based on the current reduction in the cost of electricity by the Electricity Regulatory Authority (ERA) of Uganda.

ix. The discount rate is 20%; this is the average current interest rate offered by commercial banks in the country.

x. The average quantity of *R. differens* caught is assumed to be constant for the five years and the average price of a kilogram of *R. differens* is assumed to be affected by the inflation rate in the country.

xi. All costs for items that do not exceed one year were considered as annual operating costs.

A sensitivity analysis was conducted to incorporate uncertainty into economic evaluation, a 2.87% decrease in revenue and a 2.87% increase in operating costs for the improved and traditional technique were considered at a time (Faizal et al.,2019). The choice of variation is informed by the annual inflation rate of about 2.87% in the Ugandan economy (BOU, 2020). New net present values, benefit-cost ratios and payback periods were computed for the different scenarios of changes in revenue and operating costs.

Independent samples t-tests of mean difference were conducted to compare capital expenditures, operational costs, revenue, net present value, benefit-cost ratio, payback period and the sensitivity values of the improved and current trapping technique. The analysis was carried out in R-statistical computer software version 3.5.1 (R Development Core Team, 2018) at $\alpha = 0.05$.

A one-way Analysis of variance (ANOVA) was conducted to compare the mean kilowatts of electricity consumed by LED and mercury bulbs used. Tukey's multiple comparison ($\alpha = 0.05$) was used for post hoc separation of the mean kilowatts of electricity consumed. The market price of electricity per kilowatt was used to determine the cost of electricity consumed per bulb, by multiplying the unit cost of electricity by the mean kilowatts consumed by each bulb.

6.4. Results

6.4.1. Electricity consumption of LED and mercury bulbs during trapping experiments

There was a significant difference in the electricity consumption by different light sources ($F_{3, 48.70} = 24678$, $P = 0.0001$). Electricity consumption by LED bulbs generally increased with increase in the wattage; and the consumption of electricity by the mercury 400 W bulb (9.21 ± 0.03 kWh) was significantly higher than the consumption by all the LED bulbs (Figure 6.1).

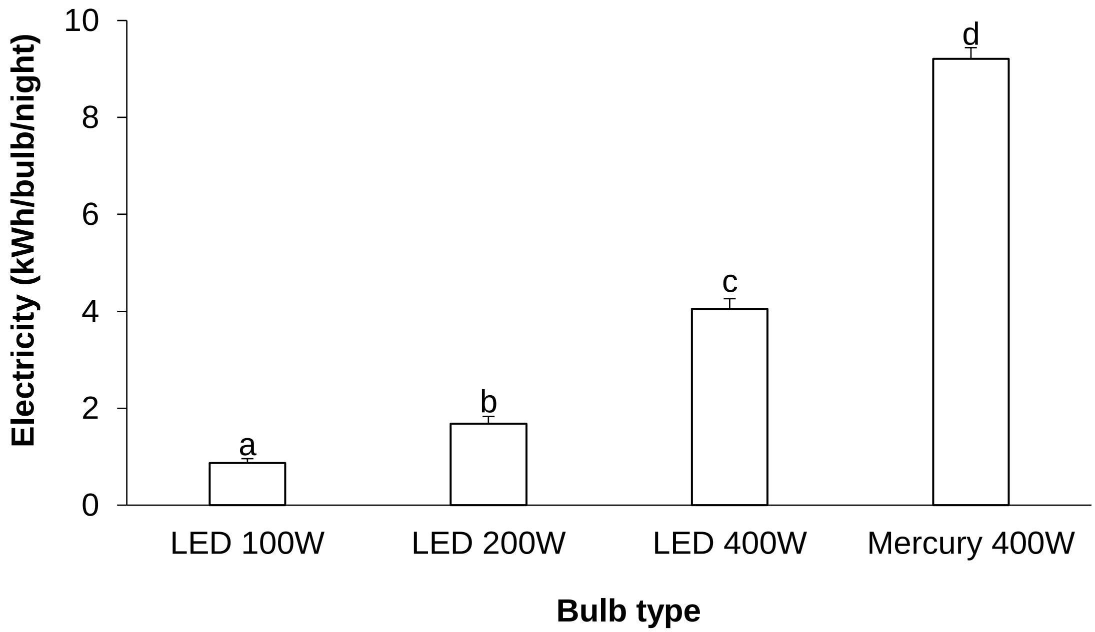

Figure 6.1: Mean (±SE) kilowatts of electricity consumed by the different types of bulbs. Bars with different letters are significantly different (α = 0.05). Error bars represent standard errors of the mean

6.4.2. Costs and revenue from improved and current trapping technique

The total capital expenditures of the improved technique were significantly higher than those of the traditional technique (t = -54682, df = 57.6, P < 0.001; Table 6.1). However, the total annual operating costs of the improved technique were significantly lower than those of the traditional technique (t = 5258.3, df = 29.6, P < 0.001; Table 6.2). Whereas total projected capital expenditures and operating costs of the improved technique were approximately four-fold those of the traditional technique in the first year, they fell to about half of those of the latter in the subsequent four years (Table 6.3). The total revenue of the improved technique was significantly higher than that of the traditional technique (t = -974.4, df = 54.7, P < 0.001) (Table 6.4). The projected revenues of the improved and traditional technique remained constant for the first two years and increased in the subsequent three years by 252 and 276 for the improved and traditional technique, respectively (Table 6.5).

6.4.3. Financial viability analysis of the improved and traditional technique

The net present value, benefit-cost ratio and payback period of the improved technique were significantly higher than those of the traditional technique (t = -9114.5, df = 29.8, P < 0.001; t = -6.9, df = 29.5, P = 0.001; and t = -3.1, df = 30.2, P = 0.005, respectively; Table 6.6).

6.4.4. Sensitivity of the profitability of improved and traditional technique

The improved and traditional technique remain profitable even when there are fluctuations in the revenue and operating costs (Table 6.7). Despite the changes in costs and revenue, the NPV remained positive and the BCR stayed above 1. A reduction of NPV of the improved technique due to a 2.87% reduction in revenue was significantly higher than that of the traditional technique (t = -6.4, df = 57.5, P = 0.003) while that of the BCR was not significantly different (t = 1.8, df = 47.3, P = 0.07). An increase in the payback period of the improved technique due to the same change in revenue was significantly higher than that of the traditional technique (t = -23.8, df = 55.9, P < 0.001). Moreover, a reduction of NPV and BCR of the improved technique due to a 2.87% increase in operating costs was significantly higher than that of the traditional technique (t = -7.2, df = 57.9, P = 0.001 and t = 6.1, df = 57.9, P = 0.009, respectively).

Table 6.1: Capital expenditures of the improved and traditional *R. differens* trapping techniques (US$)

Items	Traditional technique			Improved technique		
	Quantity	**Unit cost**	**Total cost**	**No.**	**Unit cost**	**Total cost**
Drums	20	8	160	20	34.4	688
Funnels				20	4.3	86
Iron sheets	20	6.1	122	20	6.1	122
Electric wires	35	0.4	14	35	0.4	14
LED 400W bulbs	-	-	-	3	213.3	639.9
Chokes	6	14.7	88.2	-	-	-
Poles	25	0.8	20	25	0.8	20
Total			**404.2**			**1569.9**

Table 6.2: Annual operating costs of the improved and traditional *R. differens* trapping techniques (US$)

Items	Traditional technique			Improved technique		
	Quantity	**Unit cost**	**Total cost**	**No.**	**Unit cost**	**Total cost**
Cassava flour (kg per year)	120	0.4	48	-	-	-
Water (Litres per year)	1200	0.1	120	-	-	-
Mercury 400W bulbs (No. per year)	12	16	192	-	-	-
Labour for wiring (per year)	1	24	24	1	24	24
Labour for setting traps (per day)	120	0.8	96	120	0.8	96
Labour for collecting insects (per day)	120	0.5	60	120	0.5	60
Electric power (400 W LED bulb) (per day)	-	-	-	120	2.7	324
Maintenance (lumpsum per year)	1	16	16	1	68.8	68.8
Electric power (400 W Mercury bulb) (per day)	120	6.6	792	-	-	-
Total			**1348**			**572.8**

Table 6.3: Projected capital expenditures and operating costs for the entire investment using the improved and traditional *R. differens* trapping techniques (US$)

Items	**Traditional technique**						**Improved technique**					
	Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**
Capital expenditures												
Drum	160	0	0	0	0	0	688	0	0	0	0	0
Funnel							86	0	0	0	0	0
Iron sheet	122	0	0	0	126.5	0	122	0	0	0	126.5	0
Poles	20			20.7	0	0	20	0	0	20.7	0	0
Electric wire	14	0	0	0	14.5		14	0	0	0	14.5	0
LED 400W bulb	-	-	-	-	-	-	639.9	0	0	0	0	0
Choke	88.2	0	0	0	0	0	-	-	-	-	-	-
Operating costs												
Cassava flour	0	48	49.8	51.6	53.5	55.5	-	-	-	-	-	-
Water	0	120	120	120	123.6	127.3	-	-	-	-	-	-
Mercury 400W bulbs	0	192	199	206.4	214	221.9	-	-	-	-	-	-
Labour for wiring	0	24	24.9	25.8	26.8	27.8	0	24	24.9	25.8	26.8	27.8
Labour for setting traps	0	96	99.6	103.3	107.1	111.1	0	96	99.6	103.3	107.1	111.1
Labour for collecting insects	0	60	62.2	64.5	66.9	69.4	0	60	62.2	64.5	66.9	69.4
Electric power (400 W LED bulb)	-	-	-	-	-	-	0	324	320.1	316.3	312.5	308.7
Maintenance cost	0	16	16.6	17.2	17.8	18.5	0	68.8	71.3	73.9	76.6	79.4
Electric power (400 W Mercury bulb)	0	792	782.5	773.1	763.8	754.6	-	-	-	-	-	-
Total	404.2	1348	1354.6	1382.6	1514.5	1386.1	1569.9	572.8	578.1	604.5	730.9	596.4

Table 6.4: Annual revenue from improved and traditional *R. differens* trapping techniques (US$)

Revenue	Traditional technique	Improved technique
Av. Annual catch (kg)	2760	2520
Av. Price kg^{-1}	1.1	1.3
Av. Annual revenue	3036	3276

Table 6.5: Projected revenues from the improved and traditional *R. differens* trapping techniques (US$)

Revenue	Traditional technique						Improved technique					
	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5	Year 0	Year 1	Year 2	Year 3	Year 4	Year 5
Av. Annual catch (kg)	-	2760	2760	2760	2760	2760	-	2520	2520	2520	2520	2520
Av. Price kg^{-1}	-	1.1	1.1	1.2	1.3	1.4	-	1.3	1.3	1.4	1.5	1.6
Revenue/sales	-	3036	3036	3312	3588	3864	-	3276	3276	3528	3780	4032

Table 6.6: Discounted and undiscounted cash inflows, outflows and analytical results of the improved and traditional *R. differens* trapping techniques (US$)

Items	**Traditional technique**							**Improved technique**						
	Year 0	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**	**Year 0**	**Year 1**	**Year 2**	**Year 3**	**Year 4**	**Year 5**	**Total**
Cash inflows	0	3036	3036	3312	3588	3864	17892	0	3276	3276	3528	3780	4032	17892
Cash outflows	404.2	1348	1354.6	1382.6	1514.5	1386.1	4652.6	1569.9	572.8	578.1	604.5	730.9	596.4	4652.6
Net cash flows	-404.2	1688	1681.4	1929.4	2073.5	2477.9	13239.4	-1569.9	2703.2	2697.9	2923.5	3049.1	3435.6	13239.4
Discounted cash inflows	0	2530	1265	920	747.5	644	6106.5	0	2730	1365	980	787.5	672	6534.5
Discounted cash outflows	404.2	1123.3	564.4	384.1	315.5	231	3022.5	910	477.3	240.9	167.9	152.3	99.4	2047.8
Discounted net cash flows	-404.2	1406.7	700.6	535.8	431.9	412.9	3083.7	-1549.9	2252.7	1124.1	812.1	635.2	572.6	3846.8
NPV	**3084**							**4486.7**						
BCR	**2**							**3.2**						
Payback period (months)	**2**							**7**						

Table 6.7: Sensitivity analysis of the improved and traditional *R. differens* trapping techniques

Stimulus	Traditional technique			Improved technique		
	NPV	**BCR**	**Payback period (months)**	**NPV**	**BCR**	**Payback period (months)**
2.87% decrease in revenue	2826.5	1.9	4	4302.6	3.1	16
2.87% increase in operating costs	2818.6	1.8	2	4232.7	2.9	11

6.5. Discussion

6.5.1. Electricity consumption of LED and mercury bulbs during trapping experiments

Electricity consumption approximately doubled with doubling of the wattage of LED bulbs, but the 400 W LED bulbs consumed less than half of the electricity consumed by 400 W mercury bulbs. This indicates that LED bulbs can be used on other sources of energy like solar and generators especially in some rural places where there is no connectivity to the national electricity lines. The high electricity consumption by mercury bulbs increases the variable costs inform of electricity bills, hence leading to high investment cost of the traditional technique for trapping *R. differens*. Lyatuu, (2019), reported that Umeme Limited (the largest electricity distributor in Uganda) charges Ugx.350,000 per bulb per season from trappers of *R. differens*, making electricity bills the major cost for trappers. The high electricity bills were attributed to the high consumption of electricity by the mercury bulbs that are used in trapping *R. differens* (Lyatuu, 2019). The finding of low electricity consumption by LED bulbs corroborate the report by Cohnstaedt et al., (2008) that the primary advantage of LED bulbs is decreased power consumption. However, saving about 50% of electricity as shown in data is still far from the report by Lim et al., (2012), that LED bulbs consume about 85% less energy than mercury bulbs. Therefore, investigations are required to establish ways of further saving electricity while using LED bulbs to attract *R. differens*.

6.5.2. Costs and revenue from improved and traditional technique

Our data show that the total capital expenditure of the improved *R. differens* light trap were higher than those of the traditional technique. This is attributed to the high cost of LED bulbs which are approximately thrice that of mercury bulbs of the same wattage. The funnel and wire mesh fitted to the modified drums also increased the cost of the improved technique. The improved technique, however, had lower operational costs compared to the traditional technique. This is because the materials (such as cassava flour, used cooking oil and water) that are applied daily into the open-ended drums to retain the insects in the drums (Okia et al., 2017) are not needed in the modified drums. The significantly lower consumption of electricity by LED bulbs compared to mercury bulbs, further contributes to reduced operational costs of the improved technique. The total revenue obtained from the improved technique was higher than revenue from the traditional technique yet the harvest from the two are comparable. The *R. differens* harvest from the improved technique generates more revenue because it is free from many non-target species, hence attracts a higher price than that the traditional technique.

6.5.2. Profitability of the improved and traditional technique

The data showed that trapping edible grasshoppers using both current and improved techniques is a profitable venture since the net present values are positive and the benefit-cost ratio was greater than one. This result is consistent with the findings by Agea et al., (2008), that most trappers earn over US$ 223.5 net profit per swarming season. Furthermore, Odongo et al., (2018) reported that *R. differens* trappers earn an average gross revenue of US$ 2,696 per swarming season. Whereas the current *R. differens* harvesting technique registered a shorter payback period, the improved technique recorded much higher NPV and BCR, thus emerging as the more profitable trapping technique. The higher profitability of the improved technique than the traditional technique, is attributable to the high operating costs associated with the latter and the improved quality, and hence, price of the catch from the improved technique. The longer payback period from the improved trapping technique compared to the traditional technique is due to the high investment cost of the improved technique. Generally, the improved technique was more sensitive to changes in revenue and operating costs than the traditional technique. This could be because of the high associated capital expenditures, therefore, there is a need to further improve the trapping technique using low-cost materials.

The improved trapping technique is also associated with indirect benefits that make it more advantageous than the traditional technique. Light Emitting Diode bulbs do not release mercury to the environment (Lim et al., 2012). Therefore, LED bulbs reduce the potential harmful effects of mercury on the nervous, digestive, lungs, kidneys and their corrosive effect to the skin and eyes of grasshopper trappers, neighboring people, consumers and other living organisms in the environment (Bibha and Ranjana, 2015). In addition, the modified drums filter smaller non-target insects to the bottom compartments where they are not mixed with *R. differens* and allow trappers to easily release them back to the wild by opening the door of the lower compartment. Therefore, filtering non-target insects like *Paederus* sp. which secretes pederin that causes irritation of eyes and dermatitis (Iseroson and Walton, 2012) was significant improvement in the safety of commercial harvesters, processors and consumers of *R. differens* from this hazardous insect. Filtering non-target species also contribute to conservation of these species which are food for birds and a majority of them were Noctuids which are pollinators, unlike in the traditional drums where they end-up being packed in sacks together with *R. differens.*

6.6. Conclusion and recommendation

Using the modified drums and LED 400 W bulbs for trapping *R. differens* was more profitable than using traditional drums and mercury 400 W bulbs. However, the improved technique takes a longer period to payback the capital invested. Therefore, this study recommends adoption of the improved trapping technique. The cost of the improved technique was increased by the high price of LED bulbs, hence there is need for more studies to develop less expensive but effective LED bulbs.

CHAPTER SEVEN: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

7. 1. General discussion

Trapping and marketing of *R. differens* are lucrative businesses in Uganda especially in Masaka district, employing over 800 people during the swarming seasons (Agea et al., 2008). Trapping is done using traditional light traps that consist of mercury bulbs, metallic drums and iron sheets (Okia et al., 2017). The bulbs used are high pressure bulbs that consume a lot of electric energy and pollute the environment with mercury. On the other hand, the drums used to collect *R. differens* during trapping are inefficient at retaining the catch and filtering off non-target species. To prevent escape of trapped *R. differens* from collection drums, trappers resort to applying materials like waste cooking oil on their walls, which contaminate the harvest. To address these challenges, traditional light trap were modified by (i) fitting a funnel to retain *R. differens* catch; (ii) partitioning the collection drum into three compartments by fitting a 6 × 6 mm wire mesh to retain non-target insects that are bigger than *R. differens* in the upper compartment and a 3 × 3 mm mesh to retain *R. differens* in the middle compartment while filtering smaller non-target insects to the bottom compartment; and (iii) replacing the mercury bulbs with light emitting diode (LED) bulbs which are known to be energy efficient and do not pollute the environment. The performance of the modified *R. differens* traps (modified drums and LED bulbs) compared to the traditional traps (traditional collection drums and mercury bulbs) was evaluated.

The modified drums tested in this study caught a comparable quantity of *R. differens* as the traditional drums. This suggests that the funnel in the modified drum was as effective in retaining *R. differens* catches as the materials (water, cassava flour and waste cooking oil) used by traditional trappers. The finding suggests that the modified drum can effectively avoid contamination of *R. differens* from cassava flour and waste cooking oil that is applied in traditional drums. This would improve on the quality of *R. differens* harvested and reduce the risk of carcinogenic diseases associated with waste cooking oil to consumers (Ganesan et al., 2017).

The modified drums further improved the quality of *R. differens* by reducing contamination from small non-target species. This was because the bottom mesh effectively prevented grasshoppers from going through to the bottom compartment which collected the small non-target species. Interestingly, about 85% of *Paederus* sp. which secretes pederin that causes irritation of human eyes and skins for both trappers and processors of *R. differens* (Iseroson and Walton, 2012) was collected in the bottom compartment. This was a significant improvement on the safety of *R. differens* trappers and processors from this hazardous insect. However, contamination of *R. differens* from big non-target species was not reduced because more *R. differens* was collected in the upper compartment which also contained bigger non-target species. Contamination of *R. differens* from big non-target species remains a challenge of the improved trapping technique. Therefore, the top mesh was found inessential, which necessitates further improvement of the collection drum to separate non-target insects that are of the same size or bigger than *R. differens*.

Most of the non-target insects trapped with *R. differens* were lepidopterans and a majority of them were *Achaea* sp. and *Haritalodes* sp., which were found in the bottom compartments because they were smaller than *R. differens*. This explains why *R. differens* caught in modified drums contained fewer non-targets insects compared to those from traditional drums. The health effects of some of these non-target insects to humans is not known. However, if they are not eliminated from *R. differens*, the processors spend a lot of time and more energy to sort them out. The scales from lepidopterans contaminate *R. differens,* hence requiring thorough washing which takes a lot of water and time. Therefore, use of the improved trapping technique reduces on the time spent on sorting out these species and cleaning *R. differens*. Most of the non-target insects that were trapped are known prey for birds and insects; whereas lepidopterans especially noctuids, are crop pollinators (Goldstein, 2017). Therefore, filtering some of these non-target insects to the bottom compartments of modified drums where they were not mixed with *R. differens* could allow trappers to easily release them back to the wild by opening the door of the lower compartment. This would contribute to conservation of these species, unlike in the traditional drums where they end-up being packed in sacks together with *R. differens*.

The quantity of *R. differens* caught using LED bulbs of 400 W trapped was comparable to the catch using traditional mercury bulbs of the same wattage, but with less than a half of electricity consumed by the traditionally used mercury bulbs. This implies that replacing mercury 400 W bulbs with LED 400 W lamps can save over 50% of the money spent on electricity used for trapping *R. differens*, hence increase the profits obtained from the business. This finding corroborates the report by Cohnstaedt et al., (2008) that the primary advantage of LED bulbs is low power consumption. However, saving about 50% of electricity as shown in this study is still far from the report by Lim et al., (2012), that LED bulbs consume about 85% less energy than mercury bulbs. Therefore, investigations are required to establish ways of further saving electricity while using LED bulbs to attract *R. differens*. The optimum intensity, wavelength and color of light for *R. differens* also needs to be investigated. In addition, using LED bulbs is safer because it does not release mercury to the environment (Lim et al., 2012). Therefore, substituting the mercury bulbs with LED bulbs have the potential of reducing health risks of mercury to the grasshopper trappers, neighboring people, consumers and other living organisms in the environment. The type of light source did not influence the number of non-target species caught with *R. differens*. This finding is consistent with Duehl et al., (2011) who reported that most nocturnal insects are attracted to light irrespective of its intensity and type. Therefore, efforts need to be focused on improving the collection drums to reduce the number of non-target insects trapped with *R. differens*. Trapping experiments during this study were conducted for a short period of time due to high site fees, unpredictable swarms and short warming periods. Therefore, future studies similar to the current study should consider ways of overcoming these limitations.

The improved trapping technique was found to be more profitable than the traditional trapping technique, but it takes a long period of time to get back the capital invested. This result is attributed to high initial capital for the improved technique and low variable costs. Therefore, profits from the improved trapping technique could not be realised in a single season. The finding is in agreement with Katungi et al., (2011), who reported that technologies with high initial investment are profitable when they are used over a long period of time. The improved trapping technique if adopted by trappers will increase on the profits obtained from the trapping business, but this is only true if trapping is done for a long period of time due to the high cost drums and LED bulbs. Therefore, further research is needed to develop low cost improved trapping technique that is profitable in a short run.

7.2. Conclusion

Based on the results of this study, the following conclusions are made:

i. Modified drums and LED 400 W bulbs were as effective in trapping *R. differens* as the traditional drums and mercury bulbs.
ii. Light Emitting Diode bulbs consumed 2.3-fold less electric energy than mercury bulbs of the same wattage.
iii. The upper compartment of the modified drums collected more *R. differens* than the middle and bottom compartments because *R. differens* did not effectively go through the upper mesh.
iv. The bottom compartment collected more non-target species than the upper and middle compartments, hence reducing contamination of *R. differens* which were only collected in the upper and middle compartments.
v. The modified drum was effective at filtering out most non-target species (*Heteronychus* sp., *Achaea* sp., *Haritalodes* sp. and *Paederus* sp.) from the grasshoppers compared to traditional drums
vi. LED and mercury bulbs did not show any difference in the number of non-target species found with trapped grasshoppers.
vii. Using the improved technique (modified drums and LED 400 W bulbs) for trapping *R. differens* was more profitable than using the traditional technique (traditional drums and mercury 400 W bulbs).

7.3. Recommendations

Based on this study, the following recommendations are made:

i. Modified drums and 400 W LED bulbs can replace traditional drums and mercury 400 W bulbs respectively, in order to improve trapping of *R. differens* in Uganda.
ii. The modified drum needs to be improved further by removing the upper wire mesh because most of the grasshoppers could not go through, therefore, they could easily move out of the drum when filled up.
iii. Further improvements on the modified drum to reduce contamination of the harvest by non-target insects that are of the same size or bigger than *R. differens* is necessary.

iv. There’s need to test high wattage LED bulbs to determine the optimum wattage of LED bulbs for trapping *R. differens*.

v. Further research to develop low cost but effective LED bulbs and modified drums is warranted.

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APPENDICES

Appendix 1: Questionnaire

MAKERERE UNIVERSITY, COLLEGE OF NATURAL SCIENCES, DEPARTMENT OF ZOOLOGY, ENTOMOLOGY AND FISHERIES SCIENCES

Topic: Evaluation of modified collection drums and light emitting diode bulbs for trapping the wild edible long-horned grasshopper, *Ruspolia differens* (Serville) in Uganda

Name of interviewer…………………………………………………………….

Questionnaire for collecting data on the costs and benefits of using the traditional method to trap long-horned grasshoppers (*Ruspolia differens*)

Dear respondent,

This study aims at carrying out a cost-benefit analysis of the traditional method for trapping long-horned grasshoppers and comparing it with the modified method. Information generated from this study will guide on the choice of trapping methods for commercial trappers. Therefore, you are kindly requested to provide the necessary information by answering the questions below. The information you give will be kept confidential and only used for academic purposes.

Do you accept to be interviewed? Yes/No …………...

Date of interview……………………………………...

Demographic information of respondents

1) Name of respondent …..………………………….

2) Age (a) 18-30 (b) 31-50 (c) 51 and above.

3) Sex of respondent (a) Male (b) Female

4) Educational level (a) No formal education (b) Primary (c) Secondary (d) Tertiary (e) Other (s) specify……………………………

5) Occupation other than trapping grasshoppers………………………………………………

Costs of using the traditional trap

Equipment/materials

6) Fill the table below by giving the required information about the materials/equipment you currently (2019) use in trapping *R. differens* 2

Materials/ equipment	**Quantity (Number)**	**Year of purchase**	**Cost of each material/item (Ugx)**	**Estimated current monetary value (Ugx)**	**Expected lifespan**
Bulbs					
Chokes					
Wires					
Drums					
Iron sheets					
Poles					
Others specify…..					

Electricity

7) How have you paid for electricity bills in the first and second season this year

Season	**Number of bulbs**	**Mode of payment**	**Number of tapping days**	**Amount paid**	**Amount paid for wiring and installation of bulbs and chokes**
First					
Second					

8) Do you use the same electricity for other purposes? Yes/No………………..

9) If yes to 8, how much do you think you pay for only trapping grasshoppers?.............

Setting up traps and collection of insects from the traps

10) Are you the one who sets up and collect insects from the traps? Yes/No……………………

11) If no to 10; how much do you pay for setting up traps and collecting grasshoppers from your traps per day?................

12) If yes to 10; (a) how long do you take to set up the traps and to collect trapped insects in one day?..........................

Number of traps	**Time taken**	
	Setting up the traps	Collecting the trapped insects

(b) How much would you accept to be paid if you were doing the same job to someone else?.......

13) Do you have people who help you to set up and collect insects from the traps? Yes/No……

14) If yes to 13; how many are they? ………………; and how much do you pay each of them per day?………………………

Income from the traditional traps

15) Which of the following units do you use to measure insects trapped for sale and how many have you been getting in the previous three years per season?

Unit of measure	**Quantity**						**Cost per unit**
	2017		2018		2019		
	1st season	2nd season	1st season	2nd season	1st season	2nd season	
Kilograms							
Sacks							
Basins							

Tins							
Cups							

16) Do you sort the trapped insects before selling them? Yes/No...........

17) If yes 22; (a) how long do you take to sort a sack of grasshoppers………….. (b) how much do you sale a sack after sorting………………..

18) If no to 22; (a) how much do you sell a sack of grasshoppers…………… (b) how much would you sale a sack of grasshoppers after sorting them……………..

Appendix 2: A guide for collecting data on the Costs and benefits of trapping *R. differens* using the improved trapping method

Costs of using the improved trapping technology

1) Materials/equipment for the improved trapping technology

Materials	**Cost of each material/item (Ugx)**	**Expected lifespan**
LED 400 W bulbs		
Wires		
Modified drum		
Iron sheet		
Poles		

2) Time taken to set the trap……………………..

3) Time taken to collect grasshoppers caught in the trap………………….

4) Cost of electricity per trapping night

Wattage of LED bulbs	**Cost for wiring and installation of bulbs**	**Electricity consumed (kw)**	**Cost per kilowatt**	**Total cost of electricity consumed**
400				

Benefits of using the improved trapping technology

5) Quantity (kg) and cost of grasshoppers collected from each modified drum per trapping night

Quantity (kg) per drum	**Cost per kilogram**

Appendix 2: Field activity photos

Mr. Murindwa John stannding near the traps after setting them

Mr. Mbazira Joseph and an assistant setting the traps

Setup of the experiment at Mr. Ssenyonga Abdul's trapping site