FABRICATION AND EVALUATION OF A PROBE TRAP FOR MONITORING COWPEA WEEVIL (*Callosobruchus maculatus*) INFESTING STORED COWPEA

BY

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APRIL, 2017.

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A DESSERTATION SUBMITTED TO THE SCHOOL OF POSTGRADUATE STUDIES, AHMADU BELLO UNIVERSITY, ZARIA, IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF A MASTER OF SCIENCE IN CROP PROTECTION.

DEPARTMENT OF CROP PROTECTION,
FACULTY OF AGRICULTURE,
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ZARIA, NIGERIA.

APRIL, 2017.

DECLARATION

I declare that the work in this Dissertation entitled "Fabrication and Evaluation of a Probe Trap for Monitoring Cowpea Weevil (*Callosobruchus maculatus*) Infesting Stored Cowpea" has been carried out by me in the Department of Crop Protection. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this project dissertation was previously presented for another degree or diploma at this or any other University.

_____ _____

Uzoma D. Anugwom Date
Name of Student

Confirmed by

_____ _____

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

CERTIFICATION

This dissertation entitled FABRICAION AND EVALUATION OF A PROBE TRAP FOR MONITORING COWPEA WEEVIL (*Callosobruchus maculatus*) INFESTING STORED COWPEA by ANUGWOM Uzoma Donatus meets the regulations governing the award of the Degree of Master of Science in Ahmadu Bello University and is approved for its contribution to knowledge and literary presentation.

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DEDICATION

This work is dedicated to my parents, Mr. and Mrs. Nkemjika D. Anugwom.

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ABSTRACT

Farmers are faced with a lot of problem in monitoring insect pests of stored cowpea. The standard probe trap is used to monitor *C. maculatus* infestations in stored cowpea but it is not efficient in trapping the insect due to variation in atmospheric conditions leading to inappropriate management decisions regarding the action threshold. Its perforation size (3 mm) is specific to *C. maculatus* which cannot be used for other larger bruchids like *C. subinotatus*, infecting cowpea. A research was carried out in the Entomology Laboratory of Nigerian Stored Products Research Institute, Kano, Nigeria, between March and October 2016, to examine the possibility of incorporating light into a locally fabricated probe trap, with the aim of developing an improved trap for detecting bean weevil. Six different colour lighted probe traps were evaluated, together with a control and a standard trap in order to determine the performance of respective trap in the detection of cowpea weevils. Each treatment was repeated three times, in three different insect densities: low (3 insects per kilogram of cowpea grain), medium (7 insects per kg) and high (15 insects per kg). Two weights of grains (10 kg and 100 kg) were used to determine the effect of grain volume on the performance of the fabricated probe trap. Trap catches was recorded every 24 hours for five days. Data collected was subjected to ANOVA and means were separated using SNK at 5 % confidence level. The result indicated that ambient light source was more effective in improving the performance of the modified probe trap for early detection of *C. maculatus* infesting stored cowpea, thresholds for management decisions were also determined and the fabricated trap was economically profitable; hence, objectives of the study were achieved. Commercialization of the improved probe trap is therefore recommended.

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CHAPTER ONE

1.0 INTRODUCTION

Cowpea (*Vigna unguiculata* (L.) Walp) is a popular leguminous crop in Africa which is commonly known as beans, *ewa* (Yoruba), *agwa* (Igbo), or *wake* (Hausa) in Nigeria. The grain is rich in protein and other micronutrients necessary for healthy living. Many societies endowed with cowpea have evolved different ways of utilizing the grain for food and perhaps the reason for the coinage "*naman talaka*" (poor man's meat) by Hausas of West and Central Africa (Institute for Agricultural Research Policy Brief, 2012). Rapid progress has been made in researches related to this crop, particularly since the establishment of the Grain Legume Improvement Programme at International Institute for Tropical Agriculture and the strengthening of the research program for grain legumes in a number of West African Agriculture Research Centres (Ajeigbe *et al.,* 2008). Nigeria produces more than two million tons (Adeola *et al.,* 2011) which represents 58 % of the total world cowpea production annually (Peace, 2015).

Cowpea weevil, *Callosobruchus maculatus* (F.) (Coleoptera: Chrysomelidae) is a cosmopolitan pest that causes considerable economic damage to dried cowpea and other related stored legumes, and is the main constraint to increased cowpea production and storage (Carlos, 2004). Carlos (2004) also stated that unprotected cowpea grains are often completely consumed by bruchids in the first 10 to 12 months of storage. *C. maculatus* multiplies rapidly in storage, giving rise to a new generation every month in grains at temperature of 30 ^{o}C to 35 ^{o}C and 70 % to 90 % relative humidity (RH) (Fatima *et al.*, 2016). Grains attacked have reductions in weight, nutritional compositions, viability and

virtually unfit for human consumption (Sarwar, 2015). Currently, emphases on the management of pests such as cowpea bruchid rely upon a combination of methods known as Integrated Pest Management (IPM) which are environmentally friendly to offer effective management (Lester, 2006). According to Amerika and Sharma (2004), inspection during storage is an important component of IPM, which prevents losses.

Insect probe trap, originally conceived by Loschiavo (1975) is a type of pitfall trap which is buried in grains and it catches insects which drop through small pitfall apertures into the trap. The device exploits the wandering behaviour of the insects which help in timely detection of insects in stored produce leading to timely control. This trap is a hollow metal plate tube with a series of perforations (holes) all along the sides. The top is a cap, and the bottom is a cone-like translucent plastic that screws in place. Inserted at various depths in grains, this type of trap can be extremely effective and a number of designs have been used (Barak *et al.*, 1990; Neethirajan *et al.*, 2007). Although considered of major importance, the insect probe trap is more often than not underestimated or in fact neglected, because it is time consuming and precise methods of interpreting the catch have not been adequately specified (Philips *et al.*, 2000).

Unless improved probe traps are introduced together with a strategy for their use in commercial grain storage practice, the potential benefits of any new technique will be lost. In order to modify this important IPM tool in the form available and more acceptable among local grain handlers, investigations were conducted to search for alternative means that could facilitate the performance of the device using improvised and locally available materials (Mbogo, 2013). Some factors that can influence the efficacy of an insect trap include; Light intensity and colour (David, 1992; Weinzierl *et al*., 2005; Marianne and

Rebecca, 2011; Michael and Christian, 2012; Van, 2013). Therefore, an attractant trap such as a lighted probe trap may be helpful in giving reliably early indications of the presence of bruchids that move readily in grains for necessary control measures to be initiated.

1.1 Justification

Farmers are faced with a lot of problem in monitoring insect pests of stored cowpea. The standard probe trap is used to monitor *C. maculatus* infestations in stored cowpea but it is not efficient in trapping the insect due to variation in atmospheric conditions, leading to inappropriate management decisions regarding the action threshold. Great numbers of insect species are attracted to light of various intensities or colours. Therefore, a lighted probe trap can be helpful in giving reliably early indications of the presence of bruchids that move readily in bulk grain. Many types of insect specimens collected with light traps are undamaged and so are good for research purpose. Use of light traps reduces the risks of pesticide residues in food, unlike insecticides. Insecticides are also effective but when used excessively, pests develop resistance. Light trapping, once standardized and targeted to the species of interest could be very effective in monitoring that species. The standard trap with 3 mm perforations is specific to *C. maculatus* which cannot be used for other larger bruchids like *Callosobruchus subinotatus*, infecting cowpea. Thus, there is a need for a probe trap that can be used to monitor all groups of insects infecting cowpea. The standard probe trap is also scarcely available to Nigerian grain handlers or where available, it's expensive due to high rate of foreign exchange. Furthermore, since the modified probe trap can be fabricated from locally available materials, waste can be converted into wealth.

1.2 Objectives of the Study:

To fabricate an insect probe trap for monitoring *C. maculatus* in stored cowpea.

To evaluate the performance of the modified probe trap on *C. maculatus* infesting stored cowpea.

To assess the cost benefit analysis of the fabricated probe trap.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Black Eyed Pea – *Vigna unguiculata* (L.) Walp

Cowpea, *Vigna unguiculata* L. Walp is one of several species of the widely cultivated genus *Vigna*, and one of the most important food legume crops in the semi-arid tropics covering Africa, Asia, Southern Europe, Central and South America (IAR, 2012). Cowpeas are drought-tolerant and warm-weather crop, well-adapted to the drier regions of the tropics, where other food legumes do not perform well (Singh *et al*., 2003). The major cowpea producing countries are Nigeria, Burkina Faso, Uganda, Niger, Senegal and Tanzania. According to Peace (2015), the global annual production of cowpea was about 5.4 million tons of which Africa accounts for about 5.2 million tons. Similarly, it was reported that Nigeria, being the largest producer of cowpea in the world accounts for more than two million metric tons (Adeola *et al.,* 2011) which represents about 58 % of the total world cowpea production annually (Peace, 2015).

Like many other grain crops grown in the semi-arid tropics, cowpea post-production system in developing countries is an important constraint; in particular, bruchids can destroy a granary full of cowpea in less than one year (Carlos, 2004). Even if the cowpeas are not completely consumed, consumers demand a substantial price discount before they will buy bruchid damaged cowpea (Carlos, 2004). Over the years, the difficulty faced by many developing countries is satisfying the nutritive food requirement of their teaming population amidst world population increase thus further adding to global food security concerns (FAO, 2013). The global population increase according to FAO (2013) translates

into 33 % more human mouths to be fed by the year 2050, with the greatest demand growth in the poor communities of the world (e.g. Africa). According to Alexandratos and Bruinsma (2012), food supplies would need to be increased by 60% in order to meet the global food demand by the year 2050. Thus, reduction of post-harvest losses is a critical component of ensuring future global food security (FAO, 2013).

While cowpea play a key role in subsistence farming and livestock fodder, the cowpea is also seen as a major cash crop by Central and West African farmers, with an estimated two hundred million (200,000,000) people consuming cowpea on a daily basis (Langyintuo *et al*., 2003). According to Langyintuo *et al*. (2003), at least two hundred and eighty five thousand (285,000) tons of cowpea is shipped among countries in the African region each year. Cowpea trade in West and Central Africa is clustered around Senegal and Nigeria. In Nigeria, cowpea passes from farmers to consumers through various marketing channels; farmers usually sell their surpluses to rural assemblers, who in turn sell to urban wholesalers directly or through commission agents (Carlos, 2004). Large wholesalers hold large stocks for sale to retailers when prices are high enough to pay for cost of procurement, storage, handling and a margin for profit. Factors influencing price setting are: grain quality, selling time, transport, storage, market tolls, and taxes (Carlos, 2004).

Storage losses in West Africa are substantial in spite of the use of storage insecticides by merchants, coupled with chemical hazards. Selling early in the storage season results in a loss of income because prices rise as grain legumes become increasingly scarce. However, deterioration in grain quality is not just a problem faced by farmers alone because traders at all levels within the system also suffer storage losses (Carlos, 2004).

There is no simple short cut for storing grains safely, if insects are detected as grain is about to be supplied, treatment is likely to cause some delay in the delivery, if not the total rejection of the produce upon-delivery; therefore, unless you plan for insect control and have the necessary equipment (e.g. probe trap), you should not be storing grain (Ken, 2007). Accurate information on early infestation can only be obtained through regular inspection and sampling procedures (Uma and Dharam, 2012). This is imperative in formulating sound management decisions involving the adoption of early remedial action against these bio-deteriorating agents (bruchids) or the disposal of cowpea grain with due cognizance to the condition of both the commodity and the storage facility (Ken, 2007). According to Ken (2007), problems associated with chemical control of insects and increased demands for hygienic food supplies have stimulated a search to alternate control of storage-insect pests, so as to prevent economic losses, while maintaining a healthy environment.

2.2 Monitoring as an Integrated Pest Management Tool

Insects are considered the most successful group of animals in the world and because of their morphological features, insects are found almost everywhere. It is little wonder that due to their potential adaptation, diversification and immense numbers of different species some have found ecological niche in stored grains. The advantages of small size and short generation intervals are important in their survival, because small animals need less food and oxygen compared to larger ones and can find shelter where larger animals can find none (Sethuraman and Srinivasa, 2008).

The bruchid family has received much attention in the past for several reasons (Kingsolver, 2004); demands for more food for the expanding world population and better control of stored product insects, especially those attacking comestible leguminous seeds in larders of developing countries (FAO, 2013). Storage losses can be ruinous not only from initial damage by bruchid larvae but also from ensuing invasions of other organisms (Kingsolver, 2004).

According to Peshin *et al.* (2009), the term Pest Management came about in the early 1960s, which then evolved into Integrated Pest Management (IPM). However, many aspects of IPM might have been practiced since inception of plant cultivation by early men. Discontent with a purely pesticidal approach has now led to discovery of integrated pest management system. IPM is a comprehensive approach to pest control that uses a combined means to control pests to tolerable levels while maintaining a quality environment (Lester, 2006).

According to Bruce (1981), farmers must be given economic information about principles to consider in IPM strategy, choice, and use (i.e., what factors should enter their decision process and how to weigh them). Monitoring is an important aspect of IPM in which attractants/lures and traps are useful tools for sampling insect populations in order to determine the need for control or the timing of control practices. In some instances, attractants and traps also can be used to control insect populations directly by mass trapping them or disruption of their mating activities. Using attractant traps to monitor or control insects can also indicate the effectiveness of previous insecticide applications and sometimes reduce the use of broad-spectrum or more toxic compounds (Weinzierl *et al.*,

2005). Probe traps recover insects from a much larger volume of grain than direct sampling (Buchelos and Athanassiou, 1999; Neethirajan *et al.*, 2007).

Marianne and Rebecca (2011) reported that light is an important component in the environment of insects. Some insects move towards light (photo-positive), while others move away from light and are said to be photo-negative. Light may act as a token stimulus guiding the insect to situations where it may find the optimal requirements for existence (Arnold *et al.,* 2016). Insects' response to light in most cases is to the intensity of the light (Ashfaq *et al.*, 2005) and may also depend upon the conditions to which the insect was previously exposed (David, 1992; Kingsolver, 2004). Therefore, light lures/repellants can be useful in the practice of IPM, in order to limit the use of toxic insecticides during storage of grains (Marianne and Rebecca, 2011).

Sampling should be performed at periodic intervals (sequential sampling) to gather information about population changes over time. Typically, for grains stored above 20 ^{o}C, sampling should be performed monthly. IPM relies heavily on sampling, as the use of physical and biological controls are most effective on low populations, however, if insect populations exceed an economic threshold, fumigant application is recommended. Presently, little information is available concerning the economic thresholds at which fumigants should be administered in stored grain (Uma and Dharam, 2012) but according to Johnson and Townsend (2009) once an insect infestation has become established, there are only two treatment options:

(1) Move the grain and apply a protectant during transfer or

(2) Fumigation.

2.3 Cowpea Bruchid

C. maculatus; (Coleoptera: Chrysomelidae)**, c**ommonly known as Cowpea weevil or Pulse bruchid, or *utu agwa* (Igbo) or *kokoro ewa* (Yoruba) or *Gargadoma* or *kwaron wake* (Hausa) infests seeds of wild and cultivated legumes, especially *Vigna* spp. (Kingsolver, 2004). It is the most important post-harvest (storage) pest of *Vigna* spp. throughout the tropics (Kingsolver, 2004; Van, 2013). The pest multiplies rapidly in storage, giving rise to a new generation every month in grain at temperatures of 35 ^{o}C and Relative Humidity of 70 % to 90 % (Fatima *et al.*, 2016).

2.3.1 Insect Morphology

Once inseminated by the males, adult females lay single fertilized eggs on the external surface of a bean. The larva and pupa remain inside bean seeds until emergence as adults. *C. maculatus* adults are small (3 mm long), with a body that tapers towards the head, but do not have the elongated snout of true weevils, which infest cereal grains (Christopher and Lawrence, 2014). Antenna is sub-serrate, hind femur is thick, elytra are short and do not cover the abdomen fully. It is variable in colouration, leading to confusion with other species of *Callosobruchus.* Part of the variation is due to the presence of two distinct adult forms (normal or flightless, and active or flight forms) which differ not only in their morphology, but in physiology, behaviour, etc (Kingsolver, 2004). The flightless form, having normal wings, is capable of flight but prefers to remain on the substrate of seeds in relative darkness. A population buildup with the ensuing crowded conditions in a granary situation can, due to metabolic overheating by larval activity, trigger the development of the flight form that readily flies and seeks light (Kingsolver, 2004).

The females are sometimes larger than males, females are darker overall, while males are brown but this is not true of all strains (Christopher and Lawrence, 2014). The plate covering the end of the abdomen (pygidium) is large, black with white median strip, or yellow with apical spots in females, while in males it is smaller with faint median line on the Pygidium (Kingsolver, 2004). In some strains, females are dark in colouration and the males are brown, but in other strain, both sexes are brown (Christopher and Lawrence, 2014).

a. b.

Plate I: a. adult male and b. adult female *C. maculatus* (F.)

Females of the flight (active) form is lighter in weight, their ovaries are poorly developed, and their abdomens are filled with fat bodies; also, they develop few fertile eggs. Testes of the flight males are immature at emergence but gradually develop as the individual ages (Kingsolver, 2004).

2.3.2 Life history

Female *C. maculatus* store viable sperm in their spermatheca (Christopher and Lawrence, 2014) and lays them on the seeds (Wang and Horng, 2004; Van, 2013; Christopher and Lawrence, 2014). Female *C. maculatus* adjust oviposition rates to cope with changes in host availability, laying fewer eggs when host availability is low, and hence decreases larval competition (Wang and Horng, 2004; Van, 2013). However females will sometimes

continue laying eggs onto unsuitable substrates during host deprivation. This egg dumping behaviour results in high mortality, but may be a strategy for host range expansion if preferred hosts are unavailable (Wang and Horng, 2004; Cheng *et al*., 2008). The eggs are small, oval or spindle shaped, shiny and firmly glued to the seed surface, and despite being only 0.75 mm long, are readily visible on the surface of seeds (Christopher and Lawrence, 2014).

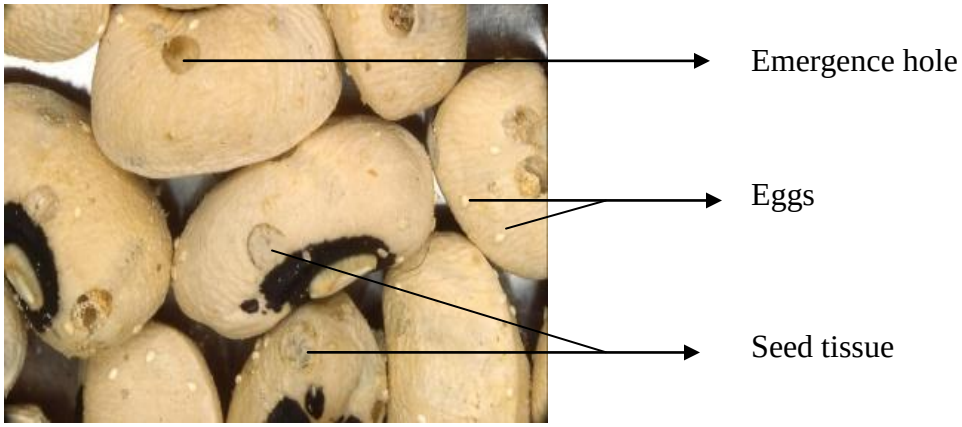


Plate II: Eggs of *C. maculatus* on cowpea, *Vigna unguiculata* (L.) Walp.

Upon hatching, the larva chews its way into the seed directly beneath the oviposition site whilst the upper surface of the egg chorion remains intact on the seed. Frass is pushed into the empty egg during feeding, causing the latter to appear white. The life cycle is completed inside the seed with the mature larva excavating underlying seed tissue, leaving a visible 'window' just below the seed testa, within which it pupates and encloses (Christopher and Lawrence, 2014).

The C-shaped larvae look like short cream-coloured maggots, and are rarely seen as they feed and develop within seeds (Christopher and Lawrence, 2014). The adult emerges

through a circular hole in the 'window' and can mate within a day (Christopher and Lawrence, 2014).

Emerging adults are well adapted to storage conditions requiring neither food nor water to live and reproduce (Wang and Horng, 2004; Cheng *et al*., 2008; Van, 2013; Christopher and Lawrence, 2014). The bruchid is sexually dimorphic and males are easily distinguished from females.

C. maculatus tolerates a range of relative humidity and temperature, making it adaptable in climates worldwide. Its developmental time varies with factors such as relative humidity, temperature, legume type, crowding, and inbreeding levels in the population. The optimum temperature for oviposition in *C. maculatus* is about 30 ^{o}C to 35 °C (Fatima *et al.*, 2016). The optimum development conditions for *C. maculatus* are around 35 °C and 90 % relative humidity (Fatima *et al.*, 2016). Again, the minimum development period for *C. maculatus* is about 3 to 4 weeks (Christopher and Lawrence, 2014; Fatima *et al.*, 2016).

2.3.3 Host range and distribution

C. maculatus has been bred on: cowpea, green gram, black gram, Bengal gram, red gram, field bean and horse gram. Cowpea and green gram was the only satisfactory food source, while other hosts resulted in longer developmental periods and high mortality (Shivanna *et al.*, 2011). It's most preferred host is Cowpea (*Vigna unguiculata*) (Olotu *et al.*, 2013; Van, 2013).

The cowpea bruchid is widely distributed in Africa, Australia, Central and South America, Europe, Northern Asia, Mediterranean, South and South-east Asia, USA and Canada

(Kingsolver, 2004; Olotu *et al.*, 2013; Van, 2013). The main method of transmission is via infested seed, either from the paddock into storage, or in contaminated seed within and between storage facilities (Singh *et al.*, 2003; Van, 2013).

2.4 History of Insect Sampling and Trapping System

Physical traps were first devised in an attempt to catch insects in numbers and thereby reduce infestation problems. According to Michael and Christian (2012), the first reference to the use of such traps seems to be in the ancient Greek Geoponika, in the first handbook of pest control. Sticky traps have been employed over the succeeding two thousand (2,000) years in attempts to control flies, moths and other insect pests (Michael and Christian, 2012). However, since the invention of IPM program, sampling has become very important in pest management (Uma and Dharam, 2012).

Sampling of insects by extraction and examination of grains may appear to be relatively simple compared to trapping, however, as the very word 'sampling' implies, only a proportion of the grain is removed for examination. Successful determination of insect infestation level by interpretation of such grain samples is dependent upon the frequency and spatial distribution of insects in the commodity (Uma and Dharam, 2012). A further key factor is the efficiency of removal of insects from any grain samples. Various works have shown that the success of detection of insects by sampling is proportional to the size of grain samples taken and that many statutory or recommended sampling frequency levels for grain are below the level which would allow the regular detection of infestation levels as high as two (2) insects per kilogram of grain (Subramanyam and Harein, 1990; Wilkin and Fleurat, 1990). At densities of 20 insects per ton, only 1 % of samples taken would be

expected to contain insects. Even the detection of insects in grains is fraught with problems and it has proven extremely difficult to devise realistic or meaningful experiments to validate and calibrate such estimates (Hagstrum *et al.,* 1991; Uma and Dharam, 2012).

An unquestioned desire for increased overall sensitivity of insect monitoring systems comes from quarantine and inspection services who wish to exclude insects and prevent those entering countries or facilities (Sethuraman and Srinivasa, 2008). Conflict may result in the chain of food usage from the initial producer to intermediate traders and the eventual processing company. Any method which is more effective than proportional removal of insects from stores would seem to be desirable (Nancy *et al.,* 2008). Therefore, currently there is the availability of different trapping systems in pest management (Nancy *et al.,* 2008; Weinzierl *et al.,* 2005), and the need for more efficient ones (Sethuraman and Srinivasa, 2008). Loschiavo (1975) constructed the perforated insect probe trap, which was effective in detecting insects in stored grains. Early discovery of infestation has been shown by the insect probe trap in grains (Neethirajan *et al.,* 2007), pheromone and food attractant traps in food warehouses and suction traps fitted with ultra-violet light (Armed Forces Pest Management Board (AFPMB), (2015). Insect light traps have been one of the most commonly used tools by professional pest control companies. Ever since, light traps and research based information about them has changed little, and basic trap designs have also changed little (Eric, 2002). Three distinct modifications in light traps can be recognized: glue boards have become design options for electrocution traps, traps have become small, and there are decorative models for use in public areas (Eric, 2002). In most cases the use of insect monitoring devices has resulted in early warning which has prevented problems caused by infestation development or failure of fumigation (Hagstrum

et al., 1991; Uma and Dharam, 2012; Plant Health Australia Limited (PHAL), 2015). In other cases, no insects were detected by conventional sampling when insects were regularly being caught in grain insect probe traps (Neethirajan *et al.*, 2007).

2.5 Standard Probe Trap

Probe traps may be the easiest and safest way to monitor stored grain insects attack (Neethirajan *et al.*, 2007). These traps are hollow metal or plastic tube with a series of perforations all along the sides.



Plate III: Picture of Standard Insect Probe Trap.

The top is a cap, and the bottom is a cone-like translucent plastic that screws in place. Insects crawling into the tube through the perforations will fall into the trap, accumulate at the pointed end of the trap and are unable to escape (Neethirajan *et al.*, 2007). Insect probe traps can be constructed to various capacities including that sizeable to silos, the probe trap is sensitive to insects such as *Tribolium spp., Cryptolestes spp., Oryzaephilus spp.* and *Callosobruchus spp.*, which are highly active insects in bulk grain. Insects like *Rhyzopertha dominica* and *Sitophilus zeamais,* which do not move around grain bulk actively are least trapped (Buchelos and Athanassiou, 1999.). The species-specific differential efficacy of

surface and sub-surface pitfall traps has been documented (e.g. Hagstrum *et al*., 1998; Buchelos and Athanassiou, 1999; Hagstrum, 2000; Carvalho *et al*., 2004; Toews *et al*., 2005; Wakefield and Cogan, 2007).

2.6 Factors Affecting Insect Trap Catch

The premise of insect monitoring program is that the number of insects captured fluctuates in response to changes in insect population density or changes in the environment (Michael and Christian, 2012; Uma and Dharam, 2012). According to Michael and Christian (2012), data from many environments with numerous insect species show that this premise is valid. IPM practitioners often struggle with the idea that factors other than pest population density can affect captures (Hagstrum *et al*. 1998; Buchelos and Athanassiou 1999; Hagstrum, 2000; Carvalho *et al*., 2004; Toews *et al*., 2005; Wakefield and Cogan, 2007; Michael and Christian, 2012; Uma and Dharam, 2012). Therefore, trap catch will be affected by the combined effect of insect population, behavior and trap design in the following ways:

2.6.1 Type of insect: Insects differ mostly according to their individual environment (aquatic or terrestrial). Adult insects typically move about by walking, flying, or sometimes swimming. Male moths can sense the pheromones of female moths over great distances. Other species communicate with sounds (crickets). *Lampyridae* in the order *Coleoptera* communicate with light (Van, 2013). Traps ought to be designed for specific type of insects (i.e. probe traps are made for grain insects) hence; type of insect can affect the effectiveness of a trap (David, 1992).

2.6.2 Temperature: Many insects survive within certain temperature and insect activities like movement, feeding, mating, oviposition etc are affected by certain temperature range

(David, 1992; Fatima *et al.*, 2016). The optimum temperature for oviposition and development in *C. maculatus* is 30 to 35 ^{o}C, (Fatima *et al.*, 2016) and according to Flinn *et al.*, (2009 and 2010) insect trap catch is significantly greater at higher grain temperature. Insect trap catch can therefore be affected positively or negatively by temperature (David, 1992; Michael and Christian, 2012).

2.6.3 Relative humidity (RH): Many insect species impressively react behaviourally to humidity gradients. Optimum relative humidity level is an issue in balancing of reasons for wanting higher or lower levels in grain stores. Low relative humidity retards insect pest activities, reduce chemical reactions such as hydrolysis and oxidation, etc (David, 1992). According to Fatima *et al.* (2016), the optimum condition for *C. maculatus* is 90 % relative humidity and the minimum is 70 %.

2.6.4 Presence of crevices: Insects hide on storage structures and vessels or produce (i.e. cracks, gaps, openings, crannies, holes, etc). Seeds can house and retain insects, preventing them from traps. The cowpea bruchid is safe from been trapped with the probe trap during the larval and pupa stages. Adult *C. maculatus* are the main target while using the probe trap; they are readily found in *V. unguiculata* grain mass (David, 1992; Wang and Horng, 2004; Van, 2013; Christopher and Lawrence, 2014).

2.6.5 Pesticide: Pesticides are substances used for attracting, seducing, and destroying, or mitigating any pest. In general, a pesticide is a chemical or biological agent (virus, bacterium, antimicrobial or disinfectant) that deters, incapacitates, kills or otherwise discourages pests. According to David (1992), presence of pesticides around traps or in trapping system can repel or attract insects to the trap, or even kill the insect before they

can reach the trap. Ironically, research showed that the use of residual insecticides (e.g. methyl bromide) resulted in fewer red flour beetles being captured in traps and measurable increases in dead adults (Michael and Christian, 2012). In many cases, pesticides can be part of a trapping system intended to kill trapped insects (David, 1992; Michael and Christian, 2012).

2.6.6 Light intensity and colour: Insects are attracted to light because light appears to them as a safe area, navigational aid, or as emergency beacon, and when in doubt, they will instinctively head for the light. Although not all insects that are attracted to light act on those impulses, but Dadmal and Suvarna (2014) revealed that Coleopterans are richly attracted by light. Certain insects are repelled by exposure to light (David, 1992) while colour is another factor that affects insect behaviour as they are attracted to certain light colours, various light intensities and wavelengths (Weinzierl *et al.,* 2005). According to Ashfaq *et al.* (2005), insects are attracted in more number on lights with short wavelengths and high frequencies and vise versa. Ultra-Violet light suction traps are designed to enhance trapping effect of the suction traps (AFPMB, 2015).

2.6.7 Food and odour: an insects' acute sense of smell enables it to find food, mates, avoid predators, and even gather in groups (Arnold *et al.,* 2016). Some insects rely on chemical cues to find their way to and from a nest, or to space themselves appropriately in a habitat with limited resources. Insects are attracted to smell of their desired food, which are readily used as baits in trapping systems (David, 1992; Michael and Christian, 2012; AFPMB, 2015).

2.6.8 Time: Insects, depending on species are found in different seasons or periods of the year, some are found during the rainy or dry season, while others may be found either in harvesting or planting seasons (Dadmal and Suvarna, 2014). This is an important factor to consider while planning trapping insects (David, 1992). Also, insect activities vary according to time of the day. Most insects are nocturnal (more active at night) while others are diurnal (active in day time). Some may be more active during sunny hour and vice versa (David, 1992).

2.6.9 Trapping duration: This influence trap catch positively or negatively, when traps are placed in short periods, targeted organisms may not be trapped (Cuperus *et al*, 1990). And on the other hand if they are left to stand for long, trapped organisms may find their escape means (David, 1992).

2.6.10 Trap position: This also affects capture rate of insects, therefore, traps should be rightly placed in order to trap an organism (David, 1992; Michael and Christian, 2012) for example, the insect probe trap is dipped vertically into grain mass at the top and centre of the grain where insect densities are high (Flinn *et al*, 2009; Flinn *et al*, 2010), and if kept horizontally will result into insects not getting trapped or escaping from the traps' reservoir (Loschiavo, 1975; Neethirajan *et al.*, 2007).

2.6.11 Insect density: Probe trap catch is highly affected by density of insects in grain mass, increasing with increase in insect densities and vise versa (Toews and Phillips, 2002).

Influences on insect behavior can be conveniently divided into two: those which are responses to external stimuli and those which are innate or driven by hormonal triggers

within the animal (David, 1992; Adriana and Lars, 2001; Micheal and Christian, 2012; Arnold *et al.,* 2016). Of course it is understood that many of the internal responses will in turn have been triggered at some point by an external factor i.e. visual stimuli (Arnold *et al.,* 2016). However, what the insect is responding to is the micro climate in its immediate vicinity (Micheal and Christian, 2012; Arnold *et al.*, 2016). This sphere of influence could be as small as the difference between adjacent interstitial grain spaces where light or colour reflections can pass through (Michael and Christian, 2012).

2.7 Insect Response to Traps

According to David (1992) and Weinzierl *et al.* (2005), as insects approach a trap randomly, they are attracted by two factors: visual or odour, or both. Visually they are attracted by light, shape, colour, or pattern, and they can also be attracted by odour for food or sex (David, 1992; Weinzierl *et al.*, 2005; Michael and Christian, 2012; Van, 2013; AFPMB, 2015; Arnold *et al.,* 2016). Also, as insects locate the trap; their ability to enter the trap is again randomly influenced by these two factors: visual or odour (David, 1992; Weinzierl *et al.*, 2005).

Michael and Christian, (2012); Weinzierl *et al.* (2005) stated that traps are designed for specific functions, most traps function to retain a trapped organism (non-return), making it appear impossible for the organism to escape (i.e. the reservoir of insect probe trap) (Neethirajan *et al.*, 2007). This is achieved either by the shape of the trapping chamber, or by fluon (slippery parts or very smooth surfaces lacking frictional force). Other traps work to kill trapped organisms, which is enhanced by:

- Electric grid for electrocution of trapped insects.

- Adhesive which aids trapping by sticking the insect thereby preventing its escape.
- Oil which is slippery to trapped organisms, as well as sticky to some insects.
- Insecticide which kills or affects the functional ability of trapped insects.

2.8 Insect Colour Vision

Insects see colours very differently from mammals, because most of them view the world in a different colour spectrum called; ultra-violet, which makes certain colours stand out (Thomas, 2011; Marianne and Rebecca, 2011). Normal sight in insects depends on two special organs; compound eyes (main organs of sight) and ocelli or simple eyes (for light and darkness detection). The compound eye is comprised of receptor units (ommatidia), which is separated by an inter-ommatidial angle, and distributed over a spherical field of view with a singular view point ((Michael, 1997; Adriana and Lars, 2001).

According to Adriana and Lars (2001) there is enormous diversity of visual conditions in which insects operate. Most insect habitats have not only differences in light intensity of several log units but also differences in the spectral composition of ambient light and in the colour signals relevant for each species (Adriana and Lars, 2001). Many insects are crepuscular; beetles particularly fly at light levels between those of room-light and moon-light (Michael, 1997). In a single insect species, different parts of the eyes are often equipped with receptors of different spectral sensitivity, and sexual dimorphisms are not uncommon (Adriana and Lars, 2001). The optical arrangements in some beetles (optical superposition) are specializations that increase the available photon numbers in dim light (Michael, 1997). Moreover, the shape of the spectral sensitivity functions and their maximum sensitivity values can differ between species (Adriana and Lars, 2001).

In many insect eyes, colour receptors are not uniformly distributed (Adriana and Lars, 2001). In superposition eyes, image at any point on the retina is the product of many lenses, unlike in apposition eyes where each receptor (ommatidia) cluster has its own lens (Michael, 1997). Colour vision, conversely, allows insects to process stimulus intensity and chromaticity independently (Adriana and Lars, 2001). It is likely that wavelength-specific behaviour indeed predated the evolution of colour vision, because numerous invertebrates without elaborate vision have more than a singular visual pigment, and they respond differently to different light intensities, wavelengths, or colours (Adriana and Lars, 2001).

2.9 Trapping and Interpreting Captures of Stored Grain Insects

The use of traps for detection, monitoring, and population estimation requires considerable knowledge of insects' biology and appropriate trap use. Trap use is essential for development of meaningful integrated pest management programs, based on insect ecology and behaviour (Michael and Christian, 2012).

The objectives of insect trapping programs in stored grain protection are to document presence or absence of a particular insect species, monitor changes in species composition, and estimate changes in insect density over time or space (Ken, 2007; Neethirajan *et al.*, 2007; PHAL, 2015). Data from such trapping programs are used to justify changes in pest management practices or to investigate the efficacy of a particular treatment (Ken, 2007; PHAL, 2015). Trap use and interpretation of insect captures provide the foundation of integrated pest management programs and may be considered a method of sampling the insect population (Ken, 2007; Neethirajan *et al.*, 2007; Michael and Christian, 2012; PHAL, 2015). Uma and Dharam (2012) stated that population density estimates and estimation methods include the following techniques:

(i) Absolute estimates (e.g. number of insects per kilogram of grain or number of moths per square meter),

(ii) Indirect estimates (mark-release-recapture methods), and

(iii) Relative estimates (number of insects caught in a sticky trap, perforated probe trap, food baited trap, etc.).

Uma and Dharam (2012) also stated that trapping relies on insects' mobility, which varies by species, environment and trapping period. The capture rate must be adjusted for time and converted to density per kilogram of grain.

Interest in, and the availability of commercially produced traps for detection of stored product insects during grain storage and food-processing is improving. New trap designs are continuously being introduced (Ken, 2007). Traps made for stored product insects generally fit into four categories: light traps, aerial traps, surface traps, and grain probe traps (Michael and Christian, 2012; AFPMB, 2015).

Light traps are wall-mounted, corner-mounted, or ceiling-suspended, and the principle of operation is that flying insects are attracted to the light and are captured or killed when they enter the trap (Michael and Christian, 2012; AFPMB, 2015). Such traps typically have a low current immobilizing electrical pulse or an electrocuting grid around the light source to kill insects, or replaceable sticky cards to hold the insects (Michael and Christian, 2012).

Grain insect probe traps are specialized pitfall traps for use in stored grain facilities such as concrete silos, steel bins, bags, and flat storages (Ken, 2007; Neethirajan *et al.*, 2007; PHAL, 2015). These traps are generally constructed of a perforated cylinder with a

reservoir attached at the bottom. The principle of operation is that the trap is inserted vertically just below the top surface of a grain mass and left in place for several days (Neethirajan *et al.*, 2007). Probe traps are rightly positioned if placed at the centre and top of grain bulk where insect densities are usually high (Flinn *et al*, 2009 and 2010). Insects wander into the trap and fall into the collection tip where they cannot escape (Loschiavo, 1975). Loschiavo, (1975) described a grain probe trap based on the idea that it would preclude grain kernels but permit entry of insects.

Data interpretation is important in order to understand that there are considerable differences in the number of traps required for various purposes. Toews *et al*., (2005) approached the problem of trap capture interpretation by focusing on both the quantity and distribution of captures in space. The researchers suggested concurrent plotting, by species, of the proportion of traps with at least one capture, overlaid with the capture mean and standard error of only the traps containing captures. Using this method, a consultant can easily assess an increasing insect population by the presence of an increasing proportion of traps, with at least one capture (Michael and Christian, 2012). Little change in the proportion of traps with at least one insect coupled with a disproportionate increase in the standard error (or no standard error), indicates a localized problem that should be handled with direct interventions. Examples could include improved exclusion, screen repairs, repair of door sweeps, improved sanitation, or targeted application of residual insecticides (Sethuraman and Srinivasa, 2008). The absence of an increasing proportion of traps with at least one capture coupled with a significant increase in the mean number of captures with a proportionate increased standard error would indicate that the population is increasing in a relatively small area. Obviously, both increasing means and proportion of traps with

captures indicates a more serious problem; depending on the situation and time of year this could be used to justify a global intervention such as fumigation (Michael and Christian, 2012).

A given set of trapping data is highly dependent on the environmental conditions in the sampling universe. Changes or fluctuations in ambient temperatures, light conditions, and movement of food produce can greatly impact trap captures. Collection of environmental data; temperature, humidity, and information about sanitation procedures, movement and turnover of food produces are of paramount importance. This information can be of critical importance when trying to interpret trapping data in both spatial and seasonal contexts (Michael and Christian, 2012).

2.10 Economic Threshold Levels for Stored Product Insects

Interpretation of trap catch is difficult because many factors influence trap catch (Hagstrum *et al.,* 1998; Michael and Christian, 2012; Uma and Dharam, 2012). According to Hagstrum and Flinn (2014), economic thresholds for insect infestation levels have been developed for raw grains commodity storage, processing plants and retail business. The threshold for traps is higher than for commodity samples because traps catch insects over time while commodity samples do not. The threshold is generally lower for processed commodities than for raw commodities because of tighter regulation. The thresholds are generally lower for insects like *Sitophilus* spp and *R dominica* that cause more damage than *Tribolium* spp. Also thresholds are lower for high value commodities like tobacco than lower value commodities like wheat.

Christian and William (2011) defined the economic injury level (EIL) as the lowest insect population density that will cause economic damage; with economic damage been defined as the amount of injury that will justify the cost of artificial control measures. Since populations reaching EIL cause economic damage, it would be advisable to take IPM actions at a level below the EIL. According to Christian and William (2011), such an approach also allows time for implementing an intervention strategy to prevent pest populations from reaching the EIL. The threshold that is below an EIL is called action threshold (AT) or economic threshold (ET), which is the pest density at which a control strategy needs to be initiated in order to suppress/manage pest populations. Hagstrum and Flinn (2014) classified a population as above or below an economic threshold of 5 insects per trap, suggesting that all insect populations with 5 and above number of insects per trap could be fumigated, while the other population with less than 5 insects per trap could be sampled again later.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Research Location

Fabrication and evaluation of the performance of the modified probe trap on *C. maculatus* infesting stored cowpea was conducted in the Entomology Laboratory of Nigerian Stored Products Research Institute (NSPRI), Kano Sub-Station (Coordinate $11^{o}30'N$, $8^{o}30'E$) Nigeria, between March 2016, to October 2016, at average temperatures of $29 \pm 3\ ^{o}C$ and 52 to 75 % relative humidity.

3.2 Trap Development

3.2.1 Materials for fabrication of probe trap

Materials used to fabricate the trap included; Anvil, Bench-vise, work/vise bench, 1 mm plumbing sockets; threaded male, threaded female and plain respectively (Conex, 2017), plastic cone (cosmetic container), sand paper, scissors, saw-blade, plastic gum, glue gum, screw driver, measuring tape, transparent ruler, coloured plastic materials (2.5 mm thick), plastic funnel, hammer, chisel, steel pipe (1 mm), perforated steel plate (from obsolete automobile silencers and heavy duty equipment casings), needle/office pins, knife, iron sponge, wood-ash, soap and water.

3.2.2 Fabrication and coupling procedure

Perforated steel material got from obsolete automobile parts were first de-coupled using chisel, hammer and anvil, and were straightened back into a flat plate, washed with wood-ash, iron sponge, soap and water to remove rusts. A dimension of 12 x 9.5 cm was

measured and cut out using a measuring tape, hammer and chisel. The measured plates were then rolled into cylindrical shape using steel pipe, hammer, bench-vise and anvil. Funnels of desired shapes and sizes were cut and glued to the threaded male plumbing socket, to make up the trapping chamber (funnel/tunnel). On the other hand, the threaded female socket was fitted to the plastic cosmetic cone using glue gum to form the reservoir. About 31.84 mm diameter circle marked out from transparent plastic material was glued to the plain socket at depth of 1.7 cm, forming the cap window of the trap.



Plate IV: Uncoupled parts during fabrication of trap.

Coupling was done by fixing the threaded male socket having the funnel with plastic gum to one end of the perforated steel cylinder, while at the other end; the plain socket with

transparent plastic (cap) was fixed with gum. After gum had dried with all trap parts well fitted, the threaded female socket (reservoir) was screwed to the perforated probe body to complete the coupling procedure. Different coloured plastic materials were used as source of coloured lights together with transparent plastic material at the cap window.

3.2.3 Trap description

Unlike the standard probe trap, the cap of the newly developed probe trap is colour lighted to evaluate the attraction of the insect to different light colours. Like most other perforated probe traps, the bottom is cone-shaped with an elongated steel cylinder made up of 4 mm diameter perforations to allow the entry of cowpea bruchids but precluding the grains. Trapped insects will pass through the funnel into a detachable reservoir from where they can be disposed.

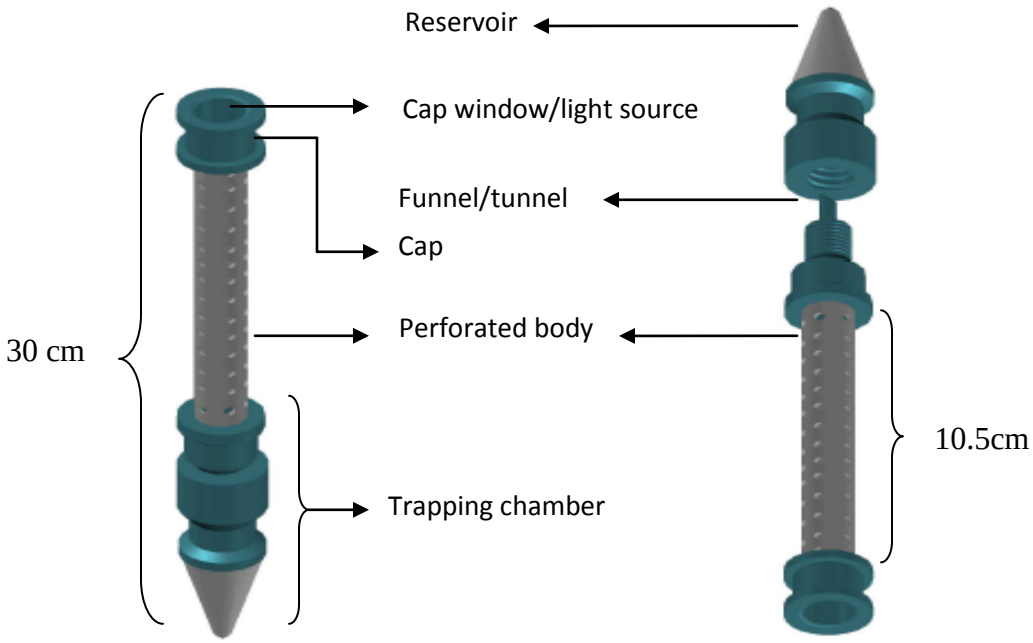


Figure 1: Components of the fabricated insect probe trap.

The receptacle (trapping chamber) is large, making it appear as a pit inside or a tunnel, which prevents captured insects from escaping (Lochiavo, 1975; Neethiraja *et al.*, 2007). Eight different types comprising of six coloured lighted traps, an unlighted control and a standard check probe trap.

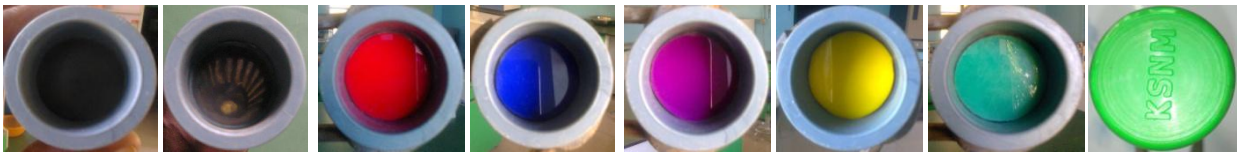


Plate V: Respective trap caps (from right to left: unlighted/control, natural/ambient, red, blue, purple, yellow, green, and standard check).

3.3 Research Materials

The experimental materials used in evaluating the performance of the modified traps were: Cowpea grains (*Kananado* variety), cowpea bruchids (0 – 24 hours of emergence), moisture analyzer (OHAUS MB25®), digital probe thermometer (HANNA® instruments), digital thermo-hygrometer (BRESSER® meade instruments Europe), Illuminance-meter (Konica Minolta® T-10, Japan), Digital calliper, freezer, kilner jars, weighing scale (CAMRY, NT-100 kg), sack bags, polyethylene bags, ropes, probe traps (KSNM India & modified/locally made), insect aspirators, insect collection bottles, storage buckets (34 cm depth with 1037.1 mm body diameter), torch lights, batteries (lionell 1.5 v) and clock.

3.4 Evaluation of Light Sources

Illuminance meter (Konica-Minolta® T10) was used to determine the intensity of coloured light coming through the caps of the different probe trap and the results were recorded in Lux using the following procedure; the illuminance meter when turned “on” was switched

to normal illuminance measurement mode. Cap (separated) with respective coloured plastic materials and with flash light were placed on the illuminance meters' "receptor window" to read individual lights' illuminance intensity and colour.

An empty cap with the transparent plastic and without any coloured material was measured in the laboratory environment using the same method as the other light sources to determine the illuminance intensity of ambient/natural light source, and same was done to determine the condition for the control/unlighted traps' cap which was blocked from light sources using sizable X-ray film material.

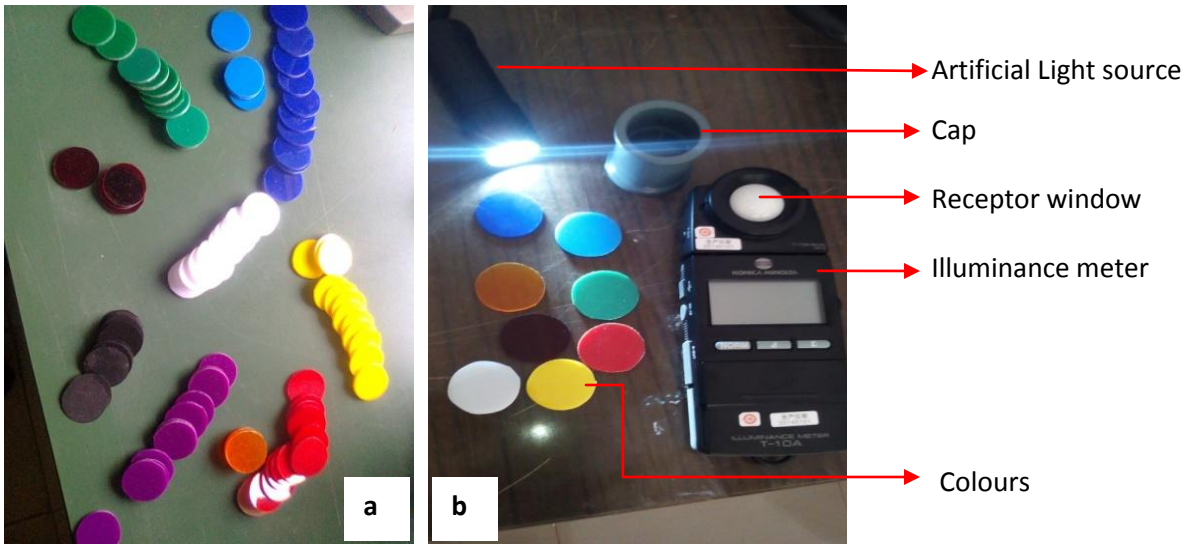


Plate VI: Different coloured plastic (a), light source, cap and illuminance meter (b).

Three hours interval measurements of illuminance intensity of light colour from the sources, and also at the end of every 24 hours, revealed the reduction in light intensity with time as a result of battery power reduction together with the average illuminance intensity for ambient/natural light source within 24 hours period.

Effects of light sources on temperature of trap and cowpea grain mass were also determined using the thermometer by switching the torch light on and plugging it into the

separated cap window, and placed on the sensor of the probe thermometer, allowing it to stand for three hours. BRESSER® thermo-hygrometer was also used as a control to determine the temperature and relative humidity of the environment.

3.5 Procurement and Disinfestations of Cowpea Grains Used for the Experiment

Cowpea grains (900 kg) collected in sealed polypropylene bags were bought from Dawanau grain market, Kano, Nigeria and disinfested in the entomology laboratory of Nigerian Stored Products Research Institute, Kano, by freezing at -20 ^{o}C to -24 ^{o}C for 72 hours to disinfest the sample (Judy and Karen, 2000; Patrick, 2013). After three days, the grains in sealed bags were removed from the freezer and left under ambient conditions for 27 hours to prevent condensational effect on the seeds before use.

3.6 Determination of Moisture Content of Cowpea Grains Used

Before the experiment, samples (50 g) were collected from the cowpea grains provided for the study, blended into powder and 10 g of the bean powder was homogeneously spread in a little-flat pan, before placing it on the moisture meters' drying pan to determine the moisture content of the grain sample to be used (Mettler, 2016). Determination of moisture content of grain was also repeated after the experiment to ascertain if the grain moisture level was affected due to artificial infestations or abiotic conditions; and moisture content of cowpea grains used for the study was determined to be 13.9 % before and 14.1 % after the experiment.

3.7 Insect Culture

Adults of *C. maculatus* were collected from an existing pure culture in Entomology Laboratory of NSPRI, Kano. Clean cowpea grains were disinfested using the cold shock method, to exterminate any insect contamination on the grains prior to culturing of the beetles. The stock culture of *C. maculatus* were raised by paring 50 adults (male and female respectively) in each two-liter kilner jar containing 2 kg of disinfected cowpea and numbering five (5 jars) to mate and oviposit. The kilner jars (cultures) were covered with netted cover to prevent the bruchids from escaping. The jars were left to stand for about 30 days until adult emergence, under prevailing laboratory conditions with temperature ranging from 29 ^{o}C – 35 ^{o}C and relative humidity of 52 to 75 %. Freshly emerged adult beetles (0 to 24 hours old) were sieved out, with stipulated numbers counted using an aspirator and placed into the collection bottles, for artificial infestation.

3.8 Trial of the Modified Trap Using 10 and 100 kg Cowpea Sample

A total of eight treatments were used and these includes different colour lighted probe traps: red, yellow, green, blue, purple, ambient, unlighted trap (control) and standard check probe traps and was repeated three times (Appendix III). There were two volumes of grains used, 10 kg and 100kg. The first volume contained three different population densities; low (30 bruchids), medium (70 bruchids), and high (150 bruchids), artificially infested into 10 kg of cowpea samples contained in grey plastic storage buckets (34 cm depth and 1037.1 mm body diameter). The traps with the different colour lighted caps including the untreated control and the standard trap were inserted into the buckets. Trap catches were recorded after every 24 hours for 5 days. The second volume (100 kg) was artificially infested with

three (3) different bruchids population densities (1500 as high, 700 as medium, and 300 as low respectively) in 100 kg disinfected cowpea samples contained in sack (poly-ethylene) bags, and catches were recorded every 24 hours for five (5) days. For both weight (10 kg and 100 kg), the low density had 3 bruchids per kg, medium had 7 bruchids and high had 15 bruchids per kg of cowpea sampled. Each population was repeated three (3) times and labeled accordingly. The bruchids in the collection bottles were artificially infested into individual cowpea (10 and 100 kg) grain samples in accordance with the labeling on the bottles and grain storage buckets. Cowpea bruchids were infested into each cowpea grain sample after each quarter of grain is placed into each labeled storage containers, or sack bag. During the experiment, electric bulbs in the laboratory were put off leaving only the natural (ambient) light source on the respective treatment.

3.8.1 Barrier control

In order to prevent insects from either leaving or entering samples, barrier was created, while also considering the working conditions. Storage plastic container covers were re-constructed for easy insertion and removal of the trap from samples without having to open the covers completely; such a container also ensured the vertical placement of traps as required for its functionality as well as preventing insects crossing (plate VII).

The buckets were grey in colour (plate VIX), and resistant to passage of ambient light which prevents insects from being disturbed by ambient light or movement of persons/objects. Also, samples in sack bags were tied with the trap in centre position, leaving the cap of the trap above to receive ambient light.

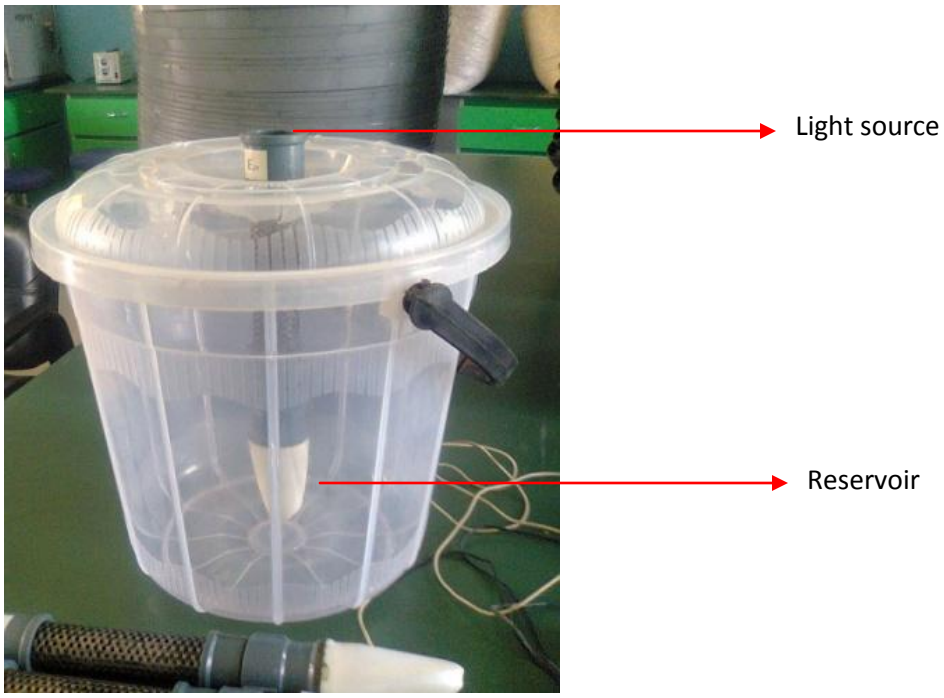


Plate VII: Vertical position of the probe trap in the storage bucket when in use.

3.8.2 Experimental layout

All the traps (72) used for the study were coded and labeled base on light source and population density of the insect infested as shown in appendix II. Insect collection bottles containing the three different insect densities were labeled as: L, M, and H for low, medium and high insect densities respectively. Plastic storage buckets as well as sack bags used were also labeled in-line with the insect collection bottles “L, M, and H” respectively for easy application of treatments as shown in plate VIII.



Plate VIII: Labeled storage buckets and insect collection bottles.

The samples after artificial infestation were arranged in Complete Randomized Design (CRD) format on laboratory benches as shown in plate VIX, while on the other hand, 100 kg samples were stacked on pallets in the laboratory.



Plate IX: Layout of samples.

3.8.3 Use of traps

Traps were pre-assigned to treatment levels, and then arranged on the laboratory bench for easy allocation to cowpea samples and data collection as shown in appendix III and plate X.



Plate X: Traps arranged for easy allocation to treatments.

Traps were first inspected for any residual sample or other contaminants, cleaned, screwed and inserted vertically into the grains through a circular window (for 10 kg samples) created on the storage buckets' cover. The traps' body was inserted vertically into the grain bulk excluding the cap of the traps, at grain depth of 26 cm (modified traps), and 21 cm (standard check trap), when fitted, colour and light source is then inserted into the caps. While in the case of 100 kg sample, traps were inserted leaving the cap above the sack bags and bag was tied to the base of traps' cap to receive ambient light.



Plate XI: Process of trap insertion into cowpea samples infested with live bruchids.



Plate XII: Process of standard check traps insertion into cowpea samples infested with live bruchids.

3.8.4 Inspection of traps

Light sources were first removed, hours directly after every 24 for 5 days, then traps were pulled out from the sacks or buckets and gently hit on a hard surface while still in vertical position to ensure trapped insects were in captured position, before un-screwing to inspect.

Considerations were made in keeping insects in place during inspection of trap catch each day as shown in plate XIII.

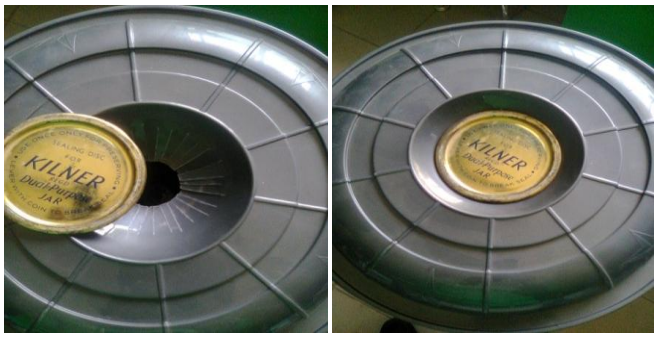


Plate XIII: Barrier control during trap inspection each day.

Water was used to wet trapped insects in the reservoir before they were discharged and counted. Traps after inspection each day were cleaned and returned into the grains and batteries were also replaced.

3.9 Data Analysis

Data collected were subjected to Analysis of Variance (ANOVA) using the SAS (2000) statistical package, version 9.0 and means were separated using the Student Newman Keuls Test (SNK) at 5 % confidence level. Correlation analysis was done to determine the relationship in trap catches between light intensities and population densities, trapping duration and population density, trapping duration and grain volume, and population densities and grain volume.

3.10 Cost Benefit Analysis

Profitability of fabricating the insect probe trap was measured in terms of gross margin and net profit in order to ascertain the economic effectiveness of fabricating the probe trap locally. A gross margin for an enterprise is its financial output minus its variable cost. Use

of gross margin in comparison of two enterprises can give a useful indication of the production and economic efficiency of an enterprise (Firth, 2002).

Where gross revenue (GR) = quantity of materials X price of materials,

Gross margin (GM) = gross revenue – total variable cost (TVC),

Return per investment (RNI) = $\frac{\text{GR}}{\text{TVC}} \text{X} \frac{1}{100}$

CHAPTER FOUR

4.0 RESULTS

4.1 Fabricated Trap and its Components

The newly fabricated probe trap has a transparent light lure window cap (figure 2), perforated body made of steel from obsolete automobile silencers, and other body parts made from locally sourced plastic materials as shown in plate XIV and XV.



Plate XIV: Modified probe traps for monitoring *C. maculatus* in stored cowpea.

The probe body of the trap has a pointed end made from cosmetic containers, beneath which is the trapping chamber made of plastic materials. The plastic funnel is lengthy, appearing as tunnel inside, and the reservoir which is 12.5 cm deep, is also detachable (plate XV).

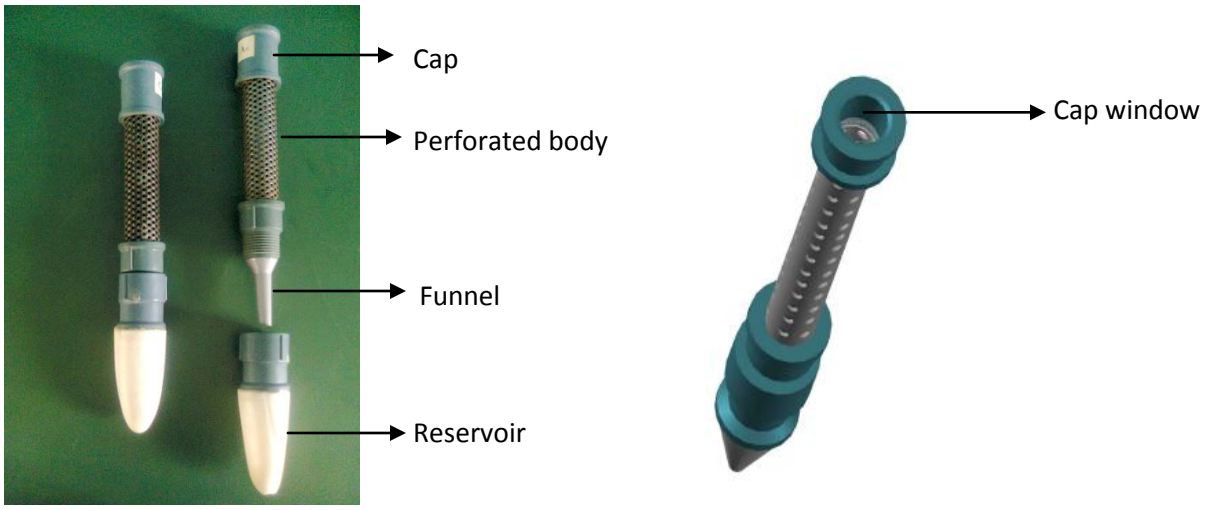


Plate XV and figure 2: Components of modified probe trap

Table 1: Variations between the Modified Trap and Standard Trap

Trap part	Standard trap	Modified trap
Trap body diameter	28.49 mm	31.84 mm
General length of trap	22.5 cm	30 cm
Length of perforated body	12.5 cm	10.5 cm
Perforation size	3 mm	4 mm
Length of trapping chamber	8.3 cm	15 cm
Length of funnel/tunnel	4.3 cm	10 cm
Size of reservoir	6.8 cm	12.5 cm
Cap length/design	1.3 cm, no cap window	4.4 cm, with cap window
Weight of trap	51.5g	154.7g

The difference between the funnel/tunnel and trapping chamber of the modified and standard check traps were as presented in figure 3 and 4 respectively.

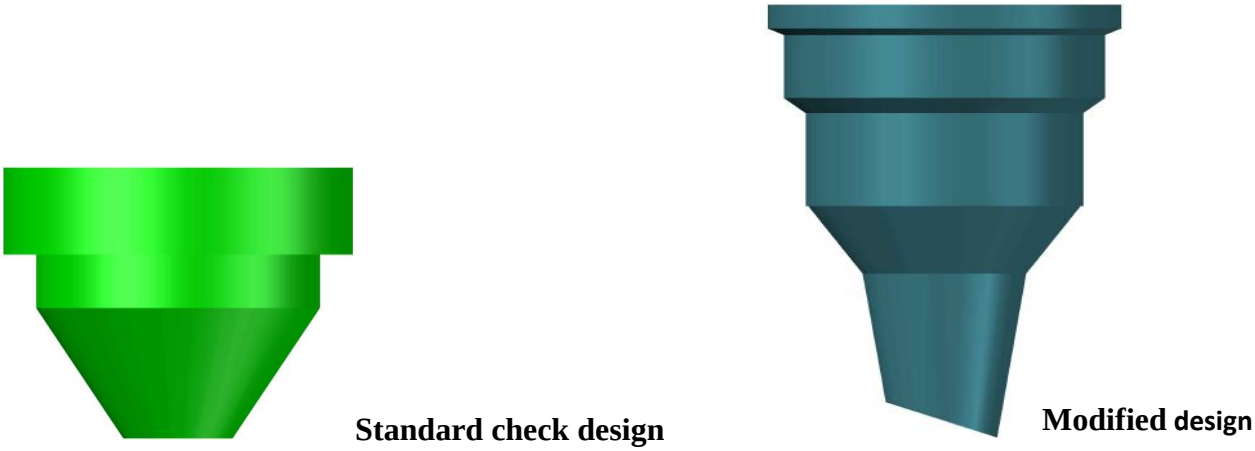


Figure 3: Difference between the funnel/tunnel of the modified and standard trap.

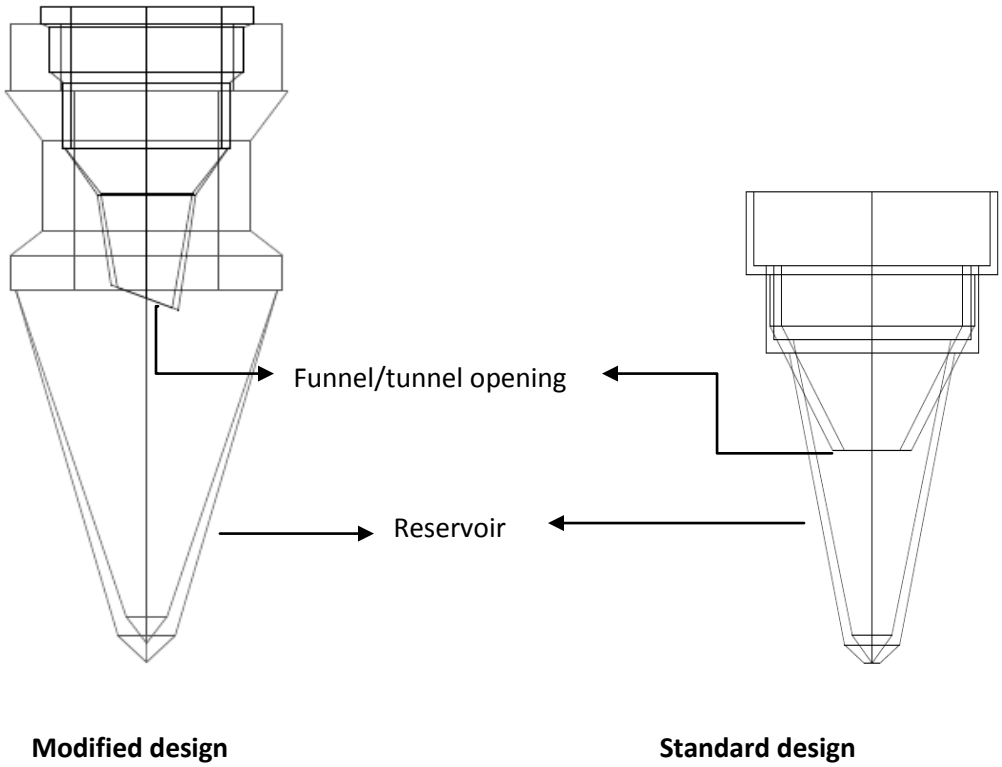


Figure 4: A schematic illustration of trapping chambers of the modified and the standard probe traps.

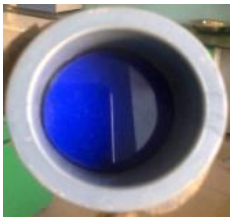


Plate XVI: Difference between the modified (A) and standard (B) probe trap.

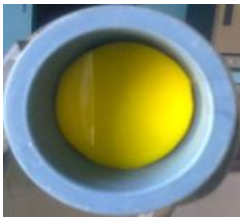
4.2 Results of Illuminance Intensity of Individual Light Colours

The result of Illuminance intensity of different coloured light sources is shown in plate XVII. The light sources also had no effect on temperature of trap and its surroundings.

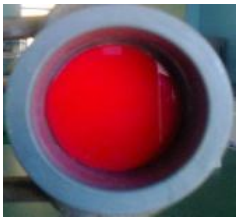

Unlighted (0.00 lx),


Blue (55.7 lx),


Purple (64.8 lx),


Yellow (1902 lx),


Ambient (14.30 lx),


Red (203.9 lx),

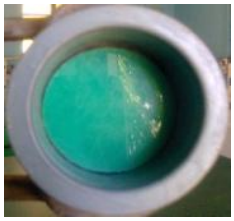

Green (193.4 lx),

Plate XVII: Coloured trap caps with illuminance value in parenthesis.

4.3 Daily Trap Catches

The result of daily trap catches presented in table 2, showed that at day one, ambient lighted trap had the best trap catch mean (21.0) and it was similar ($P \geq 0.05$) to all the other lighted traps and the unlighted control trap, but was significantly higher ($P \leq 0.05$) than the standard check trap which had the least catch mean.

At day two, ambient lighted trap was also the best mean (8.2), which was closely followed by yellow, red, blue, green and purple lighted traps and the unlighted control trap which were at par ($P \geq 0.05$) and significantly higher than the standard probe trap. However, the standard check trap was similar ($P \geq 0.05$) to the unlighted control trap.

At day three, yellow lighted probe trap was the best mean (4.8) and was closely followed by blue, ambient, purple, unlighted control, red, green and standard check traps which were at par ($P \geq 0.05$).

At day four, purple lighted probe trap had the best catch mean (2.1), it was similar ($P \geq 0.05$) to all other probe traps.

On the fifth day, the standard check trap had the highest trap catch mean of 1.8, but there was no significant difference among the traps.

Table 2: Daily Trap Catches

	Trapping Days					
Treatments	Day 1	Day 2	Day 3	Day 4	Day 5	**TOTAL**
Insect Densities						
High density	35.5[a]	10.3[a]	6.4[a]	2.5[a]	2.4[a]	57.2[a]
Medium density	11.0[b]	5.6[b]	2.5[b]	1.2[b]	0.6[b]	21.0[b]
Low density	5.8[c]	2.6[c]	1.4[c]	0.9[b]	0.5[b]	11.1[c]
SE ±	**0.75**	**0.47**	**0.35**	**0.23**	**0.25**	**0.91**
Trap Types						
Ambient	21.0[a]	8.2[a]	3.8[ab]	2.0[a]	1.6[a]	36.6[a]
Blue	20.4[a]	6.4[ab]	3.9[ab]	1.6[a]	1.0[a]	33.3[a]
Purple	20.2[a]	6.3[ab]	3.8[ab]	2.1[a]	0.8[a]	33.2[a]
Yellow	18.2[a]	7.4[ab]	4.8[a]	1.3[a]	1.1[a]	32.9[a]
Red	18.7[a]	7.2[ab]	3.2[ab]	1.8[a]	1.3[a]	32.2[a]
Green	19.9[a]	6.3[ab]	3.0[ab]	1.2[a]	0.7[a]	31.0[a]
Control	16.3[a]	4.3[bc]	3.4[ab]	1.1[a]	1.0[a]	26.2[b]
Standard	4.8[b]	3.2[c]	1.7[b]	1.2[a]	1.8[a]	12.7[c]
SE ±	**1.22**	**0.77**	**0.57**	**0.37**	**0.41**	**1.49**
Density * Trap	**	NS	NS	NS	NS	**

Note that means with the same letter are not significantly different at 5 % level of significance using SNK.

4.4 Day One Trap Catches at Different Population Density

The result of trap catches at different population density in day one is shown in table 3. The result showed that at high insect population density, ambient lighted trap had higher trap catch mean value (43.0) than all other traps, it was closely followed by blue (41.3), purple (41.0), green (39.7), yellow (38.7), red (37.7) and the unlighted control trap which were at par ($P \geq 0.05$), and significantly higher than the standard check trap (7.7).

At medium bruchids population density, there was no significant difference ($P \geq 0.05$) among the mean trap catches of all the trap types.

In low insect density, purple lighted trap had the best mean catch and it was similar to ambient, blue, yellow, red and green lighted traps as well the unlighted control, but significantly higher ($P \leq 0.05$) than the standard check trap catch mean.

Table 3: Interactive Effect of Trap Type and Population density on Number of Insect Catches on Day One

Treatments	Population Densities		
Trap Types	High	Medium	Low
Ambient	43.0^{a}	12.7^{b}	7.3^{b}
Blue	41.3^{a}	13.3^{b}	6.7^{b}
Purple	41.0^{a}	12.0^{b}	7.7^{b}
Yellow	38.7^{a}	10.7^{b}	5.3^{b}
Red	37.7^{a}	13.0^{b}	5.3^{b}
Green	39.7^{a}	12.7^{b}	7.3^{b}
Control	35.0^{a}	9.7^{b}	4.3^{b}
Standard	7.7^{b}	4.3^{b}	2.3^{c}
SE ±		**2.12**	

Means with the same letter are not significantly different at 5 % level of significance using SNK.

4.5 Total Trap Catches

The result of trap catch from different traps is presented in table 4. It revealed that ambient light source had higher trap catch mean value (36.6) than all other traps. It was closely followed by blue, purple, yellow, red and green light sources which were at par (33.3, 33.2, 32.9, 32.2 and 31.0). Low trap catch was recorded in the unlighted control trap (26.2),

however it was significantly ($P \leq 0.05$) higher than the standard probe trap which had the least trap catch mean value of about 12.7.

Table 4: Effects of different colours of light source on probe trap catch of *C. maculatus* infesting stored cowpea

Treatments	Trap Catches (mean)
Ambient/natural	36.6[a]
Blue	33.3[a]
Purple	33.2[a]
Yellow	32.9[a]
Red	32.2[a]
Green	31.0[a]
Unlighted/control	26.2[b]
Standard	12.7[c]
SE ±	**1.49**

Note: means with the same letter(s) are not significantly different at $P \leq 0.05$ using SNK.

4.6 Evaluation of Trap Catches at Different Population Densities

The result of trap catches at different population density is illustrated in table 5. The result showed that at high insect population density, ambient light trap (14.30 lx) had higher trap catch mean value (71.7) than all other traps, it was closely followed by blue (55.7 lx), purple (64.8 lx), yellow (1902 lx) and red (203.9 lx) which were at par ($P \geq 0.05$), and significantly higher than the green lighted trap. On the other hand, the green (193.4 lx) lighted trap was similar to the unlighted control trap (0.00 lx), but significantly higher than the standard probe trap which had the least mean catch (20.3).

At medium bruchids population density, there was no significant difference among mean trap catches of ambient (25.3), blue (23.0), purple (23.7), yellow (24.3), red (23.3) and

green (20.3) light sources and the unlighted control trap (15.7), but they were significantly ($P \leq 0.05$) higher than the standard check trap catch (12.0) which was the least mean. On the other hand, the standard check trap mean catch of 12.0 was similar ($P \geq 0.05$) to the mean catch of green (20.3) light trap and the unlighted control trap (15.7).

Under low bruchids population density, green lighted trap (193.4 lx) had higher trap catch mean (13.7) than all other traps but was similar ($P \geq 0.05$) to purple, ambient, blue, yellow, red and green light traps, as well as the unlighted control trap, but significantly ($P \leq 0.05$) higher than the standard check trap which had the least (5.7) mean catch.

Table 5: Interactive Effect of Trap Type and Population density on the Total Number of Insects Caught

	Population Densities		
Trap type	**Low**	**Medium**	**High**
Ambient	38 (12.7)^{d}	76 (25.3)^{c}	215 (71.7)^{a}
Blue	35 (11.7)^{d}	69 (23.0)^{c}	196 (65.3)^{a}
Purple	40 (13.3)^{d}	71 (23.7)^{c}	188 (62.7)^{a}
Yellow	36 (12.0)^{d}	73 (24.3)^{c}	187 (62.3)^{a}
Red	34 (11.3)^{d}	70 (23.3)^{c}	186 (62.0)^{a}
Green	41 (13.7)^{d}	61 (20.3)^{cd}	177 (59.0)^{b}
Control	26 (12.0)^{d}	47 (15.7)^{cd}	163 (54.3)^{b}
Standard	17 (5.7)^{e}	36 (12.0)^{d}	61 (20.3)^{cd}
SE ±		**2.58**	

Note that values in parenthesis are the mean value and means with the same letter are not significantly different at 5 % level of significance using SNK.

4.7 Correlation of Trap Catches between Population Density and Light Intensity.

Result on correlation between population densities and light intensities to trap catches is shown in table 6. There was a negative (-0.247) correlation in high insect density, medium insect density (-0.079) and also in low insect density (-0.285), which were not significant.

Table 6: Correlation Matrix of Trap Catches between Light Intensities and Population Density.

	Light intensity	High PD	Medium PD	Low PD
Light intensity	1			
High PD	-0.247^{NS}	1		
Medium PD	-0.079^{NS}	-0.342^{NS}	1	
Low PD	-0.285^{NS}	-0.021^{NS}	0.807^{**}	1

Note: PD (population density), NS (not significant), ** (highly significant) * (significant).

4.8 Correlation of Trap Catches between Trapping Duration, Population Density, and Volume of Grain

The results (table 7) showed that the correlation between trapping duration and population density was negative, and the correlation between trapping duration and volume of grain was also negative, while the correlation between population density and volume of grain was positive.

Table 7: Correlation Matrix of Trap Catches between Trapping Duration, Population Density, and Volume of Grain.

	Time	PD30L1	PD70M1	PD150H1	PD300L2	PD700M2	PD1500H2
Time	1						
PD30L1	-0.911**	1					
PD70M1	-0.940**	0.988**	1				
PD150H1	-0.854**	0.986**	0.949**	1			
PD300L2	-0.906**	0.989**	0.972**	0.986**	1		
PD700M2	-0.879**	0.978**	0.976**	0.961**	0.985**	1	
PD1500H2	-0.995**	0.896**	0.938**	0.824**	0.882**	0.868**	1

PD (population density), L (low PD), M (medium PD), H (high PD), 1 (10 kg), and 2 (100 kg).

4.9 Pest Populations Detected by the Modified and Standard Traps

The number of bruchids caught by the modified and standard trap per day in the different population densities (high, medium and low) was as shown in figure 5. Thirteen (13) bruchids was the average number catch by the modified trap per day in samples with high insect population density, while the standard caught four bruchids per day. In medium population density the average number of bruchids caught by the modified and standard trap per day was 5 and 2 respectively. Also, the average number of bruchids detected by the modified trap in sample with low insect density was 2 per day, while the standard trap caught 1 bruchid per day in low insect density.

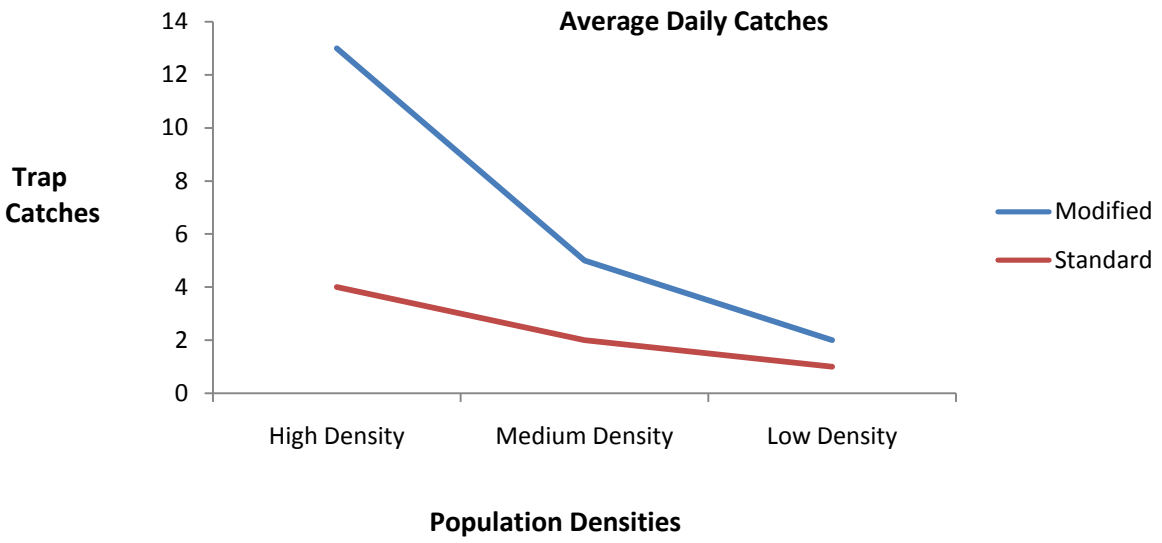


Figure 5: Average trap catches per day (24 hours interval trapping duration).

4.10 Cost and Benefits of Modified Probe Trap.

In carrying out the economic implication of fabricating the probe trap locally and cost of importing the standard probe trap, the following costs and returns (table 8) were considered. Most of the tools used can be re-used for other fabrication enterprise so depreciation was however not considered in the course of computation.

Total cost of fabricating 63 units of the modified trap was ₦ 111, 510.00, while the cost of importing 63 units of the standard trap was ₦ 170526.00. Price per unit of the modified probe trap was ₦ 1 770, while the price per unit standard check trap was ₦ 2 706.75, and the difference in costs between the modified trap and the standard check trap was ₦ 936.75.

Table 8: Cost Benefit Analysis of Locally Fabricated Probe Trap and Standard Probe Trap

LOCALLY FABRICATED PROBE TRAP					STANDARD CHECK PROBE TRAP				
Variables	**Qty**	**UP (₦)**	**TVC**	**(%)**		**Qty**	**UP(₦)**	**TVC**	**(%)**
Coloured materials	5	500	2500	2.24	Traps	63	1738.5	109525.5	64.23
Iron sponge	10	30	300	0.27	-	-	-	-	-
Labour	1	25200	25200	22.6	-	-	-	-	-
Plumbing socket	189	80	15120	13.56	-	-	-	-	-
Plastic cone	63	50	3150	2.82	-	-	-	-	-
Perforated plate	1	15500	15500	13.9	-	-	-	-	-
Plastic funnel	63	50	3150	2.82	-	-	-	-	-
Plastic gum	4	1200	4800	4.3	-	-	-	-	-
Sand paper	1	1000	1000	0.9	-	-	-	-	-
Super glue	48	50	2400	2.15	-	-	-	-	-
Transparent plastic	1	1890	1890	1.69	-	-	-	-	-
Transportation	1	5000	5000	4.48	Shipping	1	61000	61000	35.77
Anvil	1	5000	5000	4.48	-	-	-	-	-
Bench-vise	1	8000	8000	7.17	-	-	-	-	-
Chisel	1	500	500	0.45	-	-	-	-	-
Hammer	1	1500	1500	1.35	-	-	-	-	-
Knife	1	400	400	0.36	-	-	-	-	-
Measuring tape	1	700	700	0.63	-	-	-	-	-
Pins/needles	1	100	100	0.09	-	-	-	-	-
Plastic ruler	1	50	50	0.04	-	-	-	-	-
Saw blade	1	350	350	0.31	-	-	-	-	-
Scissors	2	1200	2400	2.15	-	-	-	-	-
Screw driver	2	500	1000	0.9	-	-	-	-	-
Steel pipe	1	1500	1500	1.35	-	-	-	-	-
Work-bench	1	10000	10000	8.97	-	-	-	-	-
Total cost	**403 (items)**	**₦80350**	**₦111510**	**100**		**64 (items)**	**₦62739**	**₦170526**	**100**
GR	**₦32381050**					**₦4015264**			
GM	**₦32269540**					**₦3844739**			
RNI	**₦1.90**					**₦1.35**			

Where TVC (total variable cost), UP (unit price), Qty (quantity per material used), % (percentage cost per variable item), GR (gross revenue), GM (gross margin), and RNI (return per naira investment).

CHAPTER FIVE

5.0 DISCUSSIONS

5.1 Fabricated Trap and its Components

The insect probe trap was fabricated from locally sourced materials. Different light sources on the cap were evaluated on how to trap *C. maculatus* in stored cowpea (Arnold *et al.*, 2016). The 4 mm holes on the traps body could permit entry of *C. maculatus* (3 mm) and other pulse insects of 4 mm and below in size, while precluding entry of cowpea grains into the trap (Neethirajan *et al.*, 2007). Which means the trap can be used to detect other pests of cowpea like *C. subinotatus.* Improvised plastic materials and other components used in fabricating the traps were of the desired dimension and shape, and as such fitted well.

The modified probe trap has an increased trapping chamber (both in size and length) with a cone-like end. It has a long funnel, which enables the discharge of bruchids into the reservoir as required and as well, prevent their escape from the reservoir. The reservoir is large, resembling a pit inside, while the trapping chamber (funnel) is like a tunnel inside, which means the modified trap can carry larger number of insects. Because the reservoir was detachable, and cone-like, it was easier to be inserted into grains as well as disposal of trapped insects. The locally fabricated trap was in conformity with those described by Neethirajan *et al.* (2007).

5.2 Illuminance Intensity of Respective Lights Colours

There was no heat generated by the respective light sources evaluated, though they had varied illuminance intensities, to lure cowpea bruchids. This means the torch light did not emit any heat on the trap and its surrounding and therefore, temperature of grain bulk was not affected by the use of artificially lighted probe trap in this research.

5.3 Daily Trap Catches

Trap catches were decreasing as days goes because insect densities were been reduced by the traps on daily bases, which supports findings by Toews and Phillips (2002). The ambient lighted trap was quick to reduce insect populations from samples because the insects find it more attractive which was in accordance with findings by Ashfaq *et al.,* 2005. The standard probe trap became the best mean on the fifth day because it had more insects compared to other trap samples (Toews and Phillips, 2002; Michael and Christian, 2012).

5.4 Day One Trap Catches at Different Population Densities

The fabricated traps caught relatively higher number of cowpea weevils compared to the standard probe trap because of modifications on perforation size and traps' size. Which means that the fabricated traps were improved compared to the standard check trap in detecting *C. maculatus* in stored cowpea.

5.5 Total Trap Catches

Lighted traps caught relatively higher number of bruchids compared to the unlighted traps. This means that light was effective in improving the probe trap for early detection of *C. maculatus* in stored cowpea. Findings by Ashfaq *et al.* (2005) and Dadmal and Suvarna

(2014), described that insects (Coleopterans) are attracted to light and this according to Adriana and Lars (2001); Arnold *et al.* (2016) was due to visual stimuli.

The ambient/natural light source was more effective in improving the efficiency of the trap, because it had the least illuminance intensity compared to the other light sources, which supports the finding by Ashfaq *et al.* (2005) that insects are attracted in more numbers on lights with short wavelengths and high frequencies. The result also showed that light colour had no effect on the performance of the trap, and this finding supports findings of Ashfaq *et al.,* (2005); Dadmal and Suvarna (2014) who reported that insects of the order Coleoptera are attracted to all coloured lights. By these findings, light irrespective of colour was what made the difference between the lighted traps and the unlighted traps. The unlighted/control trap was on the other hand more effective than the standard check trap which had the least trap catch mean because of variation in size and design (i.e. perforation size and general trap size) of the traps.

5.6 Evaluation of Trap Catches at Different Population Densities

Light sources were effective in attracting the bruchids due to visual stimuli (Arnold *et al.*, 2016). It also showed that effect of colour was insignificant; this according Ashfaq *et al.* (2005); Dadmal and Suvarna (2014) are because insects are attracted to all coloured lights. The ambient light source was more effective in attracting *C. maculatus* because of the reduce amount of light illuminating from the source (Ashfaq *et al.,* 2005). However, the control trap was better than the standard check trap because of modifications which improved its effectiveness in trapping *C. maculatus* in stored cowpea. This means that the locally fabricated probe trap was improved in detecting cowpea bruchids in stored grains.

5.7 Correlation of Trap Catches between Population Densities and Light Intensities

The result of correlation between population densities and intensity of light sources used showed that trap catches increased with increase in bruchids density and vise versa; this supports Toews and Phillips (2002). On the other hand, trap catches increased with decrease in light intensity and vise versa. This supports report by Ashfaq *et al.* (2005), who reported that light intensity, seemed important in attracting the insects to lighted traps.

5.8 Correlation of Trap Catches between Trapping Duration, Population Density and Volume of Grain

The results showed that irrespective of population density trap catches were affected by trapping duration. This finding was contrary to the findings by Cuperus *et al.* (1990) who reported that trap catch increased with increase in trapping duration, and this can be attributed to differences in experimental methods used; either because insect densities are been reduced by the modified traps on daily basis (Michael and Christian, 2012) or the insects were becoming less active with time (Kingsolver, 2004) or due to mortality of the bruchids with increase in time (Michael and Christian, 2012). The result also showed that irrespective of grain volume trap catches were affected by trapping duration (Cuperus *et al*., 1990). While on the other hand, result of correlation between population density and volume of grain showed that both variables affected trap catches. This was because insect densities were the same per kilogram of grain used in both volumes. The result supports Toews and Phillips (2002) who reported that probe trap catches are affected by insect density, but was at variance with Flinn *et al*, (2010) whose reports showed that because insect densities are greater at the top and centre of grains and decreasing with grain depth,

due to temperature effects (Flinn *et al*, 2009), probe trap catches are not affected by grain volume.

5.9 Pest Population Detected by the Modified and Standard Traps

Trap catches of 13 bruchids and above by the modified trap at average temperature of 29 ± 3 ^{o}C and 52 to 75 % relative humidity indicates that cowpea grains sampled had up to 15 bruchids per kilogram of cowpea grain sampled. Trap catches of 5 bruchids means that the grain sampled contained up to 7 bruchids per kilogram, while trap catches of 2 bruchids shows that there are about 3 bruchids per kilogram of cowpea grain sampled. The result of trap catches by the modified trap in medium insect density according to Hagstrum and Flinn (2014) revealed that the bruchids population was within the economic threshold (ET) or action threshold (AT) where integrated pest management actions should be taken to prevent pest population from reaching EIL (Christian and William, 2011). Hagstrum and Flinn (2014) classified a population as above or below an economic threshold (ET) when ≥ 5 insects are caught per probe trap. Therefore, other population (i.e. low) with less than 5 bruchids (i.e. 2) caught per trap could be sampled again later to determine if the population is increasing for necessary control measures to be initiated (Hagstrum and Flinn, 2014). On the other hand, the standard traps detected population below the action threshold in high and medium densities which means the new trap is improved and useful in economic threshold analysis of cowpea beetle. From the results, trap catches of 13 bruchids and above under the above mentioned abiotic conditions has reached the economic injury level (EIL) and should be fumigated.

5.10 Cost and Benefits of Modified Probe Trap

High cost (22.6 %) spent on labour can be attributed to inadequate selection of tools, which increased the amount and price of labour required during fabrication of the modified trap. The plumbing sockets as well as perforated steel plate were the most expensive materials utilized in the fabrication process because while the plumbing sockets were expensive in the local markets, the perforated steel plate was scarcely available.

Analysis of the costs also showed that the gross revenue (GR) and gross margin (GM) for profit was high in local fabrication of the probe trap than importation of the standard check probe trap, with higher return realized per naira invested compared to the standard probe trap. This was because locally sourced materials were utilized in the fabrication of the modified trap; therefore, cost of transportation was reduced as well as cost of exchange rates (Mbogo, 2013). The results support the findings by Mbogo (2013), showing that fabricating the trap locally is more profitable compared to importing the standard probe trap.

The locally made probe trap was cheap compared to the standard (imported) probe trap because of high costs imposed on shipping of the standard trap. This means that money was saved from fabricating the trap locally; hence, it is profitable to use the locally made probe trap in detecting bruchids infesting stored cowpea because it does not depend on foreign exchange rates. Indeed, fabricating the trap locally provided, in important respect, a model of how the subsidiary of locally fabricated tool can promote the development of the economy in which it is embedded which can be emulated and replicated in all developing markets (Mbogo, 2013).

CHAPTER SIX

6.0 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

6.1 Summary

With the major aim of developing an improved probe trap for monitoring/detecting *C. maculatus* in stored cowpea, the incorporation of light source into the probe trap revealed some level of improvement in detecting cowpea bruchids within 24 hours trapping duration, and was also economically profitable (cheaper) due to locally sourced materials. The best light which detected the bruchids most among the selected light sources was the natural (ambient) light source because it had the least light intensity. However, the effect of light colour was insignificant in the study. Four millimeter (4 mm) holes on the modified trap permits entry of *C. maculatus* (3 mm) and could permit other larger cowpea bruchids like *C. subinotatus*.

6.2 Conclusions

Based on the result obtained from the study, the following conclusions were made:

1. The modified probe trap was fabricated using locally sourced material.
2. Natural (ambient) light trapped 42 % of bruchids infested into samples and was the best light source to improve the performance of the probe trap among the selected light sources which means that the cost of trap production (i.e. artificial light source) as well as use-maintenance (i.e. battery) is reduced for fabricators and users.
3. The modified probe trap catch of 13 bruchids and above within 24 hours trapping period, at average temperature of 29 ± 3 ^{o}C and 52 to 75 % relative humidity has

reached the economic injury level (EIL) and should be fumigated. Catches between 12 and 5 brchids is within the action threshold (AT) and control measures must be applied to prevent pest populations from reaching the economic injury level. While catches of 2 or < 5 bruchids is below the action threshold (AT) and sampling must be done again before a growing insect population can cause economic losses.

4. The modified probe trap was ₦ 936.75 cheaper compared to the standard probe trap and had higher return per naira invested in the study area.

6.3 Recommendations

From studies carried out in this work, recommendations are that:

- Ambient light source should be incorporated into probe traps made for detecting cowpea beetles infesting stored cowpea.
- It is advisable for the people concerned (grain handlers) to use the modified and locally fabricated probe trap because the cost compared to the standard (imported) is less, it is locally available and does not depend on foreign currency.
- The new improved design of probe trap should be adopted for commercialization in order to make it readily available to users.
- Another modified trap of this design (i.e. with ambient lighted cap) can have a pheromone in order to increase its trapping ability.
- It is also desirable to extend the study to different types of stored products under various climatic conditions on other stored grain pests to determine how to best control stored grain insects using probe traps.

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APPENDIX

I

The SAS System 02:45 Wednesday, April 28, 2017 1

The GLM Procedure

Class Level Information

Class	Levels	Values
Density	3	High Low Medium
Traplight	8	Ambient Blue Green Purple Red Standard Unlighted Yellow
Rep	3	1 2 3

Number of observations 72

Dependent Variable: Day1

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Density	2	12066.86111	6033.43056	447.84	<.0001
Traplight	7	1792.00000	256.00000	19.00	<.0001
Density*Traplight	14	1248.25000	89.16071	6.62	<.0001
Error	48	646.66667	13.47222		
Corrected Total	71	15753.77778			

Dependent Variable: Day2

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Density	2	724.6944444	362.3472222	67.41	<.0001
Traplight	7	172.1666667	24.5952381	4.58	0.0006
Density*Traplight	14	88.4166667	6.3154762	1.17	0.3241
Error	48	258.000000	5.375000		
Corrected Total	71	1243.277778			

Dependent Variable: Day3

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Density	2	334.3611111	167.1805556	58.15	<.0001
Traplight	7	50.4444444	7.2063492	2.51	0.0280
Density*Traplight	14	42.9722222	3.0694444	1.07	0.4087
Error	48	138.0000000	2.8750000		
Corrected Total	71	565.7777778			

Dependent Variable: Day4

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Density	2	37.33333333	18.66666667	14.93	<.0001
Traplight	7	9.20833333	1.31547619	1.05	0.4083
Density*Traplight	14	23.33333333	1.66666667	1.33	0.2238
Error	48	60.0000000	1.2500000		
Corrected Total	71	129.8750000			

Dependent Variable: Day5

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Density	2	57.69444444	28.84722222	18.71	<.0001
Traplight	7	9.09722222	1.29960317	0.84	0.5576
Density*Traplight	14	10.52777778	0.75198413	0.49	0.9286
Error	48	74.0000000	1.5416667		
Corrected Total	71	151.3194444			

Dependent Variable: TOTAL

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Density	2	28275.44444	14137.72222	706.40	<.0001
Traplight	7	3537.20833	505.31548	25.25	<.0001
Density*Traplight	14	2259.66667	161.40476	8.06	<.0001
Error	48	960.66667	20.01389		
Corrected Total	71	35032.98611			

APENDIX

II

STD1 standard	B02 Control	C03 Green	A01 Ambient	E05 Blue	F06 Red	G07 Purple	D04 Yellow
B08 Control	A09 Ambient	STD2 standard	G14 Purple	F12 Red	D13 Yellow	E11 Blue	C10 Green
C15 Green	F16 Red	G17 Purple	A18 Ambient	STD3 Standard	B20 Control	D21 Yellow	E45 Blue
D22 yellow	C23 Green	B24 Control	E25 Blue	A26 Ambient	F27 Red	G28 Purple	STD4 Standard
G32 Purple	D30 Yellow	F31 Red	STD5 standard	C33 Green	B34 Control	A35 Ambient	E19 Blue
STD6 standard	G37 Purple	B38 Control	F36 Red	A40 Ambient	E41 Blue	D42 Yellow	C39 Green
G43 Purple	E29 Blue	STD7 Standard	D46 Yellow	C47 Green	B48 Control	A49 Ambient	F44 Red
C50 Green	F51 Red	E56 Blue	G53 Purple	D54 Yellow	A55 Ambient	STD8 Standard	B52 Control
B57 Control	D58 Yellow	E59 Blue	F61 Red	STD9 Standard	C62 Green	G63 Purple	A60 Ambient

Table 9: Code names for respective traps; A (ambient light), B (unlighted/control), C (green), D (yellow), E (blue), F (red), G (purple), and STD (standard).

APENDIX

III

S.NO	LOW	S.NO	MEDIUM	S.NO	HIGH
1	A01	1	A26	1	A49
2	A09	2	A35	2	A55
3	A18	3	A40	3	A60
4	B02	4	B24	4	B48
5	B08	5	B34	5	B52
6	B20	6	B38	6	B57
7	C03	7	C23	7	C47
8	C10	8	C33	8	C50
9	C15	9	C39	9	C62
10	D04	10	D22	10	D46
11	D13	11	D30	11	D54
12	D21	12	D42	12	D58
13	E05	13	E25	13	E45
14	E11	14	E29	14	E56
15	E19	15	E41	15	E59
16	F06	16	F27	16	F44
17	F12	17	F31	17	F51
18	F16	18	F36	18	F61
19	G07	19	G28	19	G43
20	G14	20	G32	20	G53
21	G17	21	G37	21	G63
22	STD1	22	STD4	22	STD7
23	STD2	23	STD5	23	STD8
24	STD3	24	STD6	24	STD9

Table 10: List of traps and respective treatments

APENDIX
IV



Plate XVIII: Student with Prof. L.J. Bamaiyi during inspection of trap on 28th June, 2016.

APENDIX
V



Plate XIX: Cowpea grains before the experiment.



Plate XX: Cowpea grains after the eperiment.



Plate XXI: Used torch lights after experiment.



Plate XXII: Used batteries after experiment