UNIVERSITY FOR DEVELOPMENT STUDIES, TAMALE

SUSCEPTIBILITY OF COWPEA (*VIGNA UNGUICULATA* (L.) WALPERS.) VARIETIES TO THE PULSE BEETLE (*CALLOSOBRUCHUS MACULATUS* FAB.)

AHMED SEIDU

2019

UNIVERSITY FOR DEVELOPMENT STUDIES, TAMALE

SUSCEPTIBILITY OF COWPEA (*VIGNA UNGUICULATA* (L.) WALPERS.) VARIETIES TO THE PULSE BEETLE (*CALLOSOBRUCHUS MACULATUS* FAB.)

BY

AHMED SEIDU (B.Sc. AGRICULTURE TECHNOLOGY)

(UDS/MCS/0035/16)

THESIS SUBMITED TO THE DEPARTMENT OF AGRONOMY, FACULTY OF AGRICULTURE, UNIVERSITY FOR DEVELOPMENT STUDIES, IN PARTIAL FULFILLMENT OF THE REQUIREMENT FOR THE AWARD OF MASTER OF PHYLOSOPHY DEGREE IN CROP SCIENCE

APRIL, 2019

DECLARATION

Student

I, Ahmed Seidu, hereby declare that this is the result of my own original work and that no previous submission for a degree in this university or elsewhere has been made. All sources of information have been duly cited and acknowledged by reference to the authors.

Candidate's Signature:…………………………… Date ………………………

Name: **Ahmed Seidu**

Supervisors' Declaration

I hereby declare that the preparation and presentation of this thesis was supervised in accordance with the guidelines on supervision of thesis laid down by the University for Development Studies.

Principal Supervisor's Signature:………………………. …. Date………………

Name: **Prof. Benjamin K. Badii**

Co-Supervisor's Signature:……………………………….. Date………………

Name: **Dr. Mumuni Abudulai**

ABSTRACT

The pulse beetle, *Callosobruchus maculatus* (F.) is a key pest to stored cowpea. There is limited information on host plant resistance management of this pest on cowpea in Northern Ghana. A laboratory experiment was conducted to test for varietal resistance of some improved varieties against this pest in cowpea. The experiment was laid out in a Completely Randomized Design (CRD). Seven varieties of cowpea namely; Padi-tuya, Songotra, Apagbaala, Zaayura, Bawutawuta, Marfo-tuya and a local variety obtained from farmers' stores in Nyankpala were tested. Data were collected on level of oviposition, developmental period, adult emergence, grain damage, grain weight loss, and seed viability. The results showed that the number of eggs laid on the seeds was significantly ($p < 0.05$) different among the varieties tested. More eggs were laid on seeds of the local variety, Apagbaala, Padi-tuya and Marfo-tuya, while Zaayura, Songotra and Bawutawuta recorded the least egg load. The mean developmental period was also significantly ($p < 0.05$) higher on Zaayura, Songotra and Bawutawuta, and lower on the local variety, Apagbaala, Padi-tuya and Marfo-tuya. A significantly ($p < 0.05$) higher number of adults emerged from the local variety, Apagbaala, Padi-tuya and Marfo-tuya, while Zaayura, Songotra and Bawutawuta recorded the least. Moreover, the local variety, Apagbaala and Padi-tuya recorded the highest percentage weight loss while Zaayura, Songotra and Bawutawuta recorded the least. Overall, susceptibility correlated positively with oviposition, emergence, grain damage, and grain weight loss. Zaayura, Songotra and Bawutawuta varieties consistently demonstrated high tolerance to infestation by *C. maculatus* and therefore, should be promoted for incorporation into further management/breeding programs to help minimize the high grain losses incurred by farmers during storage.

ACKNOWLEDGEMENTS

I am grateful to the Almighty Allah for providing me with good health and guidance throughout this work.

I am also grateful to my supervisors, Prof. Benjamin K. Badii and Dr. Mumuni Abudulai for their guidance that made this work a success.

My appreciation also goes to the Head of Department, Dr. Ahmed Rufai and all the lecturers in the Agronomy Department for their contributions towards the successful end of this study.

I am indebted to the Agricultural Technology Transfer (ATT) of the International Fertilizer Development Centre (IFDC) for providing a grant to support the research project.

Finally, I am grateful to all my colleagues and friends from different departments for the unity and friendliness provided me. May we stay united as friends to each other for ever.

DEDICATION

This work is dedicated to my late parents, Seidu Mahama and Fatimah Issahaku.

TABLE OF CONTENTS

CONTENTS **PAGE**

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

APPENDIX **PAGE**

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Cowpea, *Vigna unguiculata* (L.) Walpers is one of the most important leguminous crops cultivated in the tropics. It is believed to have originated from Africa and is now widely cultivated and consumed throughout the world with especially in Africa, Latin America, and Southeast Asia being the highest consumer (Abokersh and Barakat, 2015). As at 2010, an estimated 5.5 million tons of cowpea grains were produced annually from 14.5 million ha worldwide (Musa and Adeboye, 2017). In Ghana, cowpea is produced on 156,000 ha with an average yield of 310 kg/ha (Ofosu-Budu *et al.*, 2008). It is an important source of food and feed for humans and animals, respectively. Cowpea is considered as the second most important food legume after groundnut (Egbadzor *et al.*, 2013).

All parts of cowpea plant have specific uses at different stages of its growth. The young leaves, immature pods and seeds are used as vegetables. The fresh leaves are prepared in a form of spinach, mixed with coconut milk or fresh cream or groundnuts, or mixed with stews as in most traditional households around the world (Tindal, 1983). Sometimes, the leaves are dried and preserved; later they are used in preparing soup especially when there are no fresh vegetables. Alternatively, this can also be used as a meat substitute. This gives it the name ‘’poor man’s meat’’ (Fox and Young, 1982). The grain contains approximately 21-25% protein and 50-67% starch. In areas such as West and Central Africa, the fodder is cut and stored for subsequent sale at the peak of the dry season (Bressani, 1985; Quin, 1997). As a vegetable crop, the chemical composition of cowpea corresponds with that of most edible legumes (Coetzee, 1995). The seeds also contain small amounts of B-carotene equivalents, thiamin, riboflavin, vitamin A, niacin, folic acid and ascorbic acid (Kay, 1979; Tindal, 1983). The use of cowpea seeds as a vegetable provides an inexpensive source of protein in many rural diets. The dried pulse may be cooked together with other vegetables to make a thick soup, or ground into a meal or paste, before preparation in different ways (Kay, 1979; Allen, 1983; Quass, 1995). The seeds of cowpea after harvest are mostly stored for subsequent use. It is considered as a valuable and dependable commodity as it provides income for farmers and traders through the sales of the grains (Singh, 2002; Langyintuo *et al.*, 2003). Cowpea has the ability to restore soil fertility after harvest through its atmospheric nitrogen fixation (Carsky *et al.*, 2002; Tarawali *et al.*, 2002; Sanginga *et al.*, 2003).

1.2 Problem statement

Despite the economic importance of cowpea, it still suffers great loses especially at the storage level due to insect pest infestation. This limits its usable supply and consumption (Wright, 1986). Storage pests cause heavy economic losses to the grains with their impact being more devastating especially in developing countries like Ghana where options for their control are limited (Badii *et al.*, 2013A and B; Ekeh *et al.*, 2013). (Gomez, 2003) reported that percentage grain damaged in Northern Ghana by *C. maculatus* was as high as 80%. Percentage grain weight loss as a result of the damage caused by *C. maculatus* ranged between 24.0% and

29.4% in susceptible cowpea varieties without protection (Badii *et al*., 2013 B). *Callosobruchus maculatus* (F) is regarded as the most important storage pest of cowpea due to the high level of damage it inflicts on the grain (Fatemeh *et al*., 2009 and Upadhyay; Ahmad, 2011). It is cosmopolitan and the most destructive pest of stored pulse grains that causes severe post harvest and economic losses to farmers and traders (Caswell, 1981; Nalini *et al*., 2012). Its infestation in unprotected stored grains can cause complete damage, rendering it unsuitable for consumption within few months in storage (Badii *et al*., 2013A and B; Musa and Adeboye, 2017).

Infestation of cowpea grains by this weevil usually starts from the field and then this is carried over to the store where populations build up especially in poorly dried and unprotected grains. The insect lays its eggs directly on the pods and seeds, and it takes between 3 to 7 weeks to complete its life cycle depending upon the substrate and the environmental conditions (Beck and Blumer, 2014). Huge losses of between 20 and 50% have been reported on stored cowpea due to infestation and damage by *C. maculatus* (Mbaiguinam, 2006). Sometimes the losses could rise up to 100% within 6 months of storage without protection due to the insect's short life cycle and reproductive capacity (Kingsolver, 2004; Beck and Blumer, 2007, 2014; Mkenda and Ndakidemi, 2014). Control of this pest is therefore necessary to increase and sustain production and preservation of cowpea.

1.3 Justification

There are several synthetic insecticides for the control of *C. maculatus* in cowpea (Dimetry *et al.*, 2007; Sarwar, 2015), but their use has not been sustainable. Perhaps, this is due to their high costs and unavailability in local markets (Joseph *et al.*, 2016) as well as the associated health problems such as residues of the pesticide active ingredients in the grains (Mogbo *et al.*, 2014). Environmental risks such as the elimination of beneficial insects and the development of resistance by the insect pests could also be another reason (Mundi *et al.*, 2012; Jibrin *et al.*, 2013; Musa and Adeboye, 2017). In order to reduce the over-reliance on chemicals for bruchid pest control, the search for host plant resistance in cowpea seeds, which is an environmentally safer and cheaper alternative to the killer synthetic insecticides, has intensified in recent years.

Host plant resistance to pests offers sustainable option in insect pest management (Kananji, 2007). The use of resistant cowpea cultivars provides a simple, cheap and attractive alternative to the synthetic chemical insecticides for the reduction of bruchid damage. It requires minimum knowledge by farmers, cost less to farmers and also enhances the effectiveness of other pest management methods such as cultural and biological control (Thomas and Waage, 1995; Badii *et al.*, 2013; Augustine *et al.*, 2016).

The CSIR-Savanna Agricultural Research Institute (CSIR-SARI) has developed a number of improved cowpea varieties namely, Padi-tuya, Apagbaala, Songotra, Zaayura, Bawutawuta and Marfo-tuya. These varieties were tested for their high yielding and other agronomic traits (SARI annual report, 2013; CCVRRG, 2015). However, from available literature, the resistance of these improved varieties to infestation of *C. maculatus* is yet to be documented. Hence, the need to study the responses of these varieties to *C. maculatus* infestation.

1.4 Objectives

The objectives of the study were to;

- Evaluate the susceptibility of seven cowpea varieties to infestation and damage by the pulse beetle, *Callosobruchus maculatus* (F.) under storage conditions.
- Determine the effect of the varieties on the survival, growth and developments as well as their impact on the seed weight, quality and viability were evaluated in the laboratory.

CHAPTER TWO

2.0 LITERATURE REVIEW

a) Taxonomy of cowpea

Cowpea [*Vigna unguiculata* (L) Walp.] is a dicotyledonous crop with 22 chromosomes (2n=2x=22) (Timko and Singh, 2008). It belongs to the order Resales, Family Leguminosae and subfamily Papilionoideae. Cowpea is a member of the tribe Phaseoleae and subtribe Phaseolinae. There are four species groups in the genus largely distributed throughout the world (IGLIC, 1987). The major groupings consist of the African subgenera, *Vigna* and *Haydonia*, the Asian subgenus *Ceratotropis*, and the American subgenera *Sigmoidotropis* and *Lasiopron.*

Initially, divisions were made into several subgenera under this genus based on morphological characteristics, extent of genetic hybridization or reproductive isolation as well as geographic distribution of species where cultivated cowpea was placed in the subgenus *Vigna.* Mungbean and blackgram under this division were also placed in the Asian subgenera. *Vigna unguiculata* subspecies *unguiculata* includes four cultivated groups: *unguiculata*, *biflora* (or cylindrical), *sesquipedalis*, and *textilis* (Timko and Singh, 2008). *Vigna unguiculata* subspecies *dekindiana*, *stenophylla*, and *tenuis* were considered to be the immediate wild progenitors of cultivated cowpea, and form the major portion of the primary gene pool of the cowpea crop.

Members of the subspecies *dekindiana*, *stenophylla*, and *tenuis* were also considered part of this gene pool. A secondary gene pool was constituted by other wild subspecies like pubescence that do not readily hybridize with some degree of reproductive (pollen) sterility (Sariah, 2010) demanding an embryo rescue for reproduction. There existed several classifications of the forms under this group, where, based on existing variations, some are considered as botanical varieties by some scientists and subspecies by others.

Currently, the most accepted classification is the one which recognizes this group as *Vigna unguiculata* (L.) Walpers subspecies *unguiculata*; *Vigna unguiculata* (L.) Walpers subspecies *sesquipedalis* (L) Verde.; *Vigna unguiculata* (L) Walpers subspecies *cylindrica* (L) van Eseltine; *Vigna unguiculata* (L.) Walpers subspecies *dekindiana* (Harms.) Verde.; and *Vigna unguiculata* (L.) Walpers subspecies *mensensis (*Schweinf.) Verde. (IGLIC, 1987).

b) Origin of cowpea

There is very weak archeological evidence with regards to the origin of cowpea. This has led to contradicting views leading to the endorsement of Africa, Asia and South America as the origin of the crop.

One of the earliest works concerning the origin of crop species was written by de Candolle (1886). De Candolle listed the disciplines that could assist in the identification of origin as botany, archeology, history and physiology. He stressed the importance of the presence of wild forms of the crop plant and for shadowed the concept of centres of diversity as centres of origin. This was then developed later by Vavilov (1951). Vavilov considered that the area of maximum diversity of a crop plant is also likely to be the centre of domestication of the species. It was anticipated that with most crop plants wild types would be present in the areas where the crop originated and that a high frequency of dominant genes would be found there.

De Candolle further discussed at length the origin of the names given to crops. Where a crop is known by a name derived from the language of another region. It was suggested that the crop may have been introduced from areas where that language is spoken. But de Candolle's concept must be applied cautiously because of the possibilities that migrants may have applied their own names to local crops. Also, when the commerce of an area is run mainly by one national group, the names used by the group may have become dominant throughout a region. The latter problem is well illustrated in South East Asia where cowpeas are known by a Chinese name e.g, Sitao in the Philippines (Burkill, 1935 and Brown, 1954).

Confusion may also arise because local names often refer to a type of crop e.g. beans, not a species and two examples relevant to cowpeas can be given. Firstly, the word Katjang, is applied to many species of beans and is reported the origin of the botanical name of pigeon pea, *Cajanus cajan* (De, 1974). Secondly, the antiquity of cultivation of cowpeas in the Mediterranean area is indicated by the fact that according to Burkill (1935), they were known to the ancient Greeks and Romans as "Phaseolors" or "Phaseolus" although in the past the name was thought to refer to the haricot bean and was borrowed from the genus Phaseolus.

Much of the confusion surrounding the origin of cowpeas resulted from the predominance of different cultivated types in different regions; subspecies *unguiculata* in Africa, *cylindrica* in Asia and *sesquipedalis* in South East Asia but all three subspecies can be found in each region. De Candolle noted that the abundance of a species is not a proof of its antiquity, a point that can be well illustrated by the widespread cutivation of wheat and soybean in North America. Over all, the evidence favours Africa as the origin of cowpea, but this does not exclude the possibility that the subspecies cylindrica and sesquipedalis were developed by selection in Asia after introduction from Africa (Westphal, 1974).

Secondary centres of genetic diversity in cowpeas occurred elsewhere in Africa, perhaps both in the medium to low elevations, savannah and coastal areas of East Africa and further south. Cowpeas have been cultivated or gathered in tropical Africa since pre-historic times and must have reached Egypt, Arabia and India very early. The early Greeks and Romans also knew of cowpeas as they were introduced into West Indies in the 16th Century reaching the United States around 1706 (Purseglove, 1968).

As with most crop plants, wild types would be present in the areas where the crop originated. Also, a high frequency of dominant genes of the crop would be found there as has been found in West Africa (IITA, 1982). Widespread distribution of the wild cowpea is one of the strongest lines of evidence favoring Africa as the origin of the crop. According to some literature, cowpea was introduced to the Indian subcontinent approximately 2,000 to 3,500 years ago from Africa, whilst others stated that before 300 BC, cowpeas had reached Europe and possibly North

Africa from Asia (OECD, 2015). Within Africa, some favored Ethiopia as the region of origin (Vavi1ov, 1951; Steel, 1972). Others limited the origin of cowpea to West Africa (Piper 1913; Rachie and Roberts, 1974; Rawal, 1975). Some people are also of the view that cowpea originated from Southern Africa. With the presence of most primitive wild cowpea varieties, speculations had it that the Northern part of the Republic of South Africa happens to be the centre of speciation of cowpea (PGC, 2014). Further hypothesis suggested that the species moved northwards from the Transvaal to Mozambique and Tanzania, where the subspecies pubescence evolved (OECD, 2015).

Among these revelations, the West African origin seems more convincing since both wild and cultivated species abound in this region (IITA, 1982). Timko *et al.*, (2007) stated that West Africa appears to be the major center of diversity of cultivated forms of cowpea and as such, cowpeas appear to have originated from West Africa. In this region, it is very likely to have originated from Nigeria where the wild and weedy species abound both in the savannah and forest zones (Rawal, 1975; IITA, 1982).

c) Morphological description of cowpea

Morphological viability in the cultivated forms of cowpea (*V. unguiculata*) is enormous (Porter *et al.*, 1975). It is an annual herb with varying growth forms. Growth habit ranges from erect, determinate non-branching types to prostrate or climbing, indeterminate profusely branching forms. Usually, cowpea is indeterminate under favorable conditions. Cultivated cowpeas are usually glabrous annual herbs with a strong, deep taproot and many branches formed from it on the surface of the soil. The root nodules are smooth and spherical, about 5mm in diameter, being numerous on the tap root and main branches, but sparse on the smaller roots (IITA, 1982).

Leaves are alternate and trifoliate with one symmetrical terminal leaflet ranging from circular to hastate in shape and two asymmetrical leaflets. Petioles vary from 3 to 25cm in length with swollen pulvinus at the base of the petioles. Stipellae are one per each lateral leaflet and two for the terminal leaflet (IITA, 1982). The first pair of leaves is basic and opposite while the rest are arranged in an alternate pattern and are trifoliate. The leaves are usually dark green in colour and exhibit considerable variation in size (6 to 16 x 4 to 11 cm) and shape (linearlanceolate to ovate). The leaf petiole is 5 to 25 cm long.

Sterms are striate, smooth or slightly hairy, cylindrical but slightly ribbed, twisting, sometimes hollow and glaborous with scattered minute spinelets. Pigmentation on the stem varies from none or localized purple pigment at nodes to solid purple. Each node subtends two ovate, cordate or lanceolate, appendaged. The axillary bud may develop into a branch or flower-bearing peduncle.

Flowers are arranged in racemose or intermediate inflorescences at the distal ends of 5 to 60 cm long peduncles. The peduncles are slightly twisted and ribbed. Flowers are borne in alternate pairs, with usually only two to a few flowers per inflorescence. Flowers are conspicuous, self-pollinating, borne on short pedicels. The inflorescence is an unbranched auxiliary raceme bearing several flowers at the terminal end of peduncles. The rachis is contracted with paired fertile flowers and abortive flowers that exude a sweet liquid when shed (Ojehomon, 1968). Bracts are one per flower and deciduous at early stages of floral development. Pedicels are very short with two deciduous bracteoles. The calyx is longitudinally ribbed, tabular with 2 to 15cm long sub equal lobes that are sometimes purple. The corollas may be white, dirty yellow, pink, pale blue or purple in colour. The corolla is papillionaceous with an erect standard petal spreading at the time of flower opening. The pigmentation pattern of the corolla varies from white to solid mauve with yellow spots near the base of the standard petal (IITA, 1982). The wings are adherent to the boat shaped keel enclosing the androecium and gynoecium. The stamens are diadelphous with the vexi1lary stamen free and nine fused, forming a tubular sheath around gynoecium.

The length of the pods may vary from less than 11cm to more than 100cm with many locules per pod. They also vary in size, shape, colour and texture. They may be erect, crescent-shaped or coiled. The pigmentation pattern of the pod varies from green to green with a purple tip and/or suture and valves, to purple or brown at the immature stage; and straw to straw with dull black splashes to deep purple or brown at maturity (IITA, 1982). They are usually yellow when ripe, but may also be brown or purple in colour.

Seeds vary considerably in size, shape and colour. Usually the number of seeds per pod may vary from 8 to 20. The seeds are relatively large (2 to 12 mm long) and weigh 5 to 30 g/100 seeds. The testa may be smooth or wrinkled; white, green, buff, red, brown, black, speckled, blotched, eyed (hilum white, surrounded by a dark ring) or mottled in colour.

What is considered essential part of the plant in cowpea is determined by the intended end use of the plant. A number of the plant parts could be important, i.e. seed, young leaves or seed and pod (PGC, 2014).

d) Geographic distribution of cowpea

The range of cowpea is geographically wide, from warm temperature thorn to moist through tropical thorn to wet forest life zones (Gomez, 2003). Cowpea cannot be grown for grain in cooler regions due to its sensitivity to frost. It grows best in hot areas and can produce a yield of one ton seed and five tons hay per hectare with as little as 300 mm of rainfall (Gomez, 2003). Long taproot and mechanisms such as turning the leaves upwards to prevent them from becoming hot and closing the stomata, give cowpea an excellent drought tolerance (Van Rij, 1999).

Cowpea is considered more tolerant to drought than other leguminous crops such as soybean and mungbean because of its tendency to form a deep taproot (Gomez, 2003). It has a competitive niche in sandy soils, it does not tolerate excessively wet conditions, and should not be grown on poorly drained soils.

One of the more remarkable things about cowpea is that it thrives well in dry environments. Though cultivars that do well in the moist savannahs are also available, cowpea becomes the best crop for the sahelian and the dry savannah zones (Lowenberg-DeBoer, 1998). The reason is that available cultivars produce a crop with as little as 300 mm of rainfall. The length of cowpea growing season varies with type. It takes 100 days in determinate type, 110 days in semideterminate, and 120 days in ranking type. The climate will also have an effect on the length of the growing season. The hotter the weather, the shorter the maturity period (Van Rij, 1999).

Cowpea production has spread to East and Central Africa, India, Asia, South and Central America, and now to the whole world with movement of people through trade (IITA, 1982). Cowpea is now grown throughout the tropics and subtropics and has now become part of the diet of millions of people in these regions and the world at large.

e) Economic importance of cowpea

Cowpea is considered an important staple food in West Africa and other parts of the world where it is largely produced for domestic consumption (Singh *et al.*, 1997). The grain complements that of cereals as food for people through its enhancement of the quantities and qualities of proteins and vitamins (Timko *et al.*, 2007; OECD, 2015). The grains contain about 23% protein and 57% carbohydrate, while the leaves contain between 27 and 34% proteins. It is often referred to as the poor man's meat because of its high level of food protein (Singh *et al.*, 2005; Abdullahi *et al.*, 2016). The grains also have substantial levels of folic acid which is a critical source of vitamin for humans' especially pregnant women as it prevents the occurrence of neural tube defects such as spinal bifida in infants (OECD, 2015). Fresh and dry grains of early season cowpea cultivars serve as an important source of food during the "hunger period" that occurs a month or two before the main cereal crops harvest in many local communities of the savannah zones of West Africa. This has therefore made the cowpea grain the most important part of the cowpea plant for human consumption. The seeds are consumed whole either after cooking or after milling and the flour used in various recipes such as 'Tubani' and 'Koose' in many parts of Africa (Abudulai *et al.*, 2006; OECD, 2015). The leaves and residue also serve as an important source of nutritious feed for livestock.

Cowpea is considered as a valuable and dependable commodity that provides income for farmers especially, the rural poor farmers and traders through the sales of the grains (Singh, 2002; Langyintuo *et al.*, 2003). It is the second most important food legume after groundnuts in terms of area under cultivation, quantity produced and consumption annually in Ghana (Egbadzor *et al.*, 2013).

The crop is also considered an important component of the farming systems in many parts of West Africa due to its ability to restore soil fertility for succeeding cereal crops such as maize, sorghum and millet, through its atmospheric nitrogen fixation (Carsky *et al.*, 2002; Tarawali *et al.*, 2002; Sanginga *et al.*, 2003). The grains and vines also serve as raw materials for the cowpea production and processing industry.

f) Production estimates of cowpea

Cowpea is the most important pulse in tropical Africa, and it is cultivated along the southern fringes, from the west coast to East Africa and southwards. Exact figures on area cultivated for cowpeas in Africa are not available because of lack of reliable statistical enumeration. This is partly true because cowpea is often cultivated in mixtures with other crops and it is mostly used for home consumption. Also the portion marketed is often not done through official channels where trade statistics can be maintained (Simon *et al.,* 2015). Similarly unreported kitchen garden, vegetable use and inaccurate reporting as "dry beans" may under-estimate real production by as much as 50% or more (Simon *et al.,* 2015). This suggests the equivalent of more than 2 million metric tons under-estimate production of cowpea annually (Rachie and Rawal, 1976).

Cowpea is widely produced throughout the tropics. However, Central and West Africa are the world leading producers accounting for more than 64 % of the estimated 3.3 million tons of cowpea grains produced annually from 12.5 million ha worldwide. Central and West Africa account for about 8 million ha, followed by about 2.4 million ha in Central and South America, 1.3 million ha in Asia and 0.8 million ha in East Africa. With these estimates, only a small proportion of the cowpea produced enters the international trade. Africa produces over 75% of the crop, principally in Nigeria, Ghana, Uganda, Niger and Senegal (Rachie and Rawal, 1976). In Africa, Nigeria is known to be the world's leading cowpea producing country, followed by Brazil, Senegal, Ghana, Mali and Burkina Faso (Langyintuo *et al.*, 2003). Seed yields are very low often ranging from 0.15 - 0.2 t/ha (Rachie *et al.*, 1975), but under favorable conditions, productivity levels of 1,500 to 2,000 kg/ha are realized within 60 to 70 days from planting (Rachie, 1972).

World cowpea production as reported by Francis (2009) was estimated at 3,319,375 MT and 75% of that production from Africa (FAOSTAT, 2000). West Africa is reported to be the key cowpea producing zone, mainly in the dry savanna and semi-arid agro ecological zones (Francis, 2009). Niger and Cameroon are also significant producers of cowpea in West Africa whilst United States of America (USA) is a substantial producer and exporter in the developed countries.

On the basis of available data, sustained increased production over the last 10 years was recorded from Malawi, Niger, Nigeria, Upper Volta and Zimbabwe. In Tanzania, production declined in the early 1970's but in the late 1970's it showed considerable improvement in production (Simon *et al.,* 2015). In Uganda total production deteriorated sharply after 1975. Production also declined in Madagascar and Senegal during the 1970's. In Ghana, cowpea covers 156,000 ha (IITA, 1993). However, an average yields of the crop (310 kg/ha) is among the lowest in the world (Ofosu-Budu *et al*., 2008). Meanwhile, the crop is one of the widely cultivated legumes, mainly in the savannah and transition zones of Ghana (CRI, 2006). According to Lowenberg-DeBoer (2000), Ghana is one of the major producers of cowpeas in the world but in addition, it imports about 10,000 MT annually. About 30 percent of the Ghanaian imports are from Burkina Faso and the rest from Niger (Francis, 2009). In Accra, the large, rough coated Niger cowpea sells for a premium, but it needs to be marketed quickly because it does not store well in the humid coastal climate.

Research conducted on the damage recorded on stored cowpea in the Northern Region of Ghana revealed that the number of farmers who stor their cowpea decreased over the storage season as they either sold or consumed their cowpea grains after harvest. Few farmers keep their cowpea in store over the entire storage season. These levels of damage were recorded on farmers' cowpea, under normal storage conditions and management. Weight loss remains lower than expected but observed levels of damage caused significant storage losses, hence price reduction (Gomez, 2003).

With these damages on cowpea, efforts have been made to improve cowpea production in all agro-ecological zones of Ghana through various means including the introduction of new improved varieties. Recently, several studies conducted by CSIR-SARI evaluated the performance of improved cowpea varieties in several ecological zones with emphasis on the Northern Region of Ghana (CCVRRG, 2015). In selecting appropriate varieties for different agro-ecological environments, it is pertinent to know how resistant these new varieties are to storage pests in order to avoid the post harvest losses due to the storage pest attack.

g) Postharvest constraints of cowpea

Cowpea grains have a lot of setbacks after harvest. Factors such as threshing, drying, cleaning and packaging all affect cowpea in one way or the other if not done properly. Cowpea seed can easily be injured when too dry or threshed too roughly. This injured seed might produce weak, stunted plants and other abnormalities when planted. In Africa, different multipurpose machines have been developed for cleaning, drying and milling of food commodities including cowpea. However, these machines are expensive and unavailable to cowpea farmers especially the subsistence farmers in the local communities who produce cowpea. Pathogenic infections that lead to mold growth when the grains are not properly dried to the safest moisture level before storage is another setback to cowpea.

Beside the above mentioned setbacks to cowpea after harvest, there are postharvest loss attributes such as insect pests' infestations too. These insect pests attack on the grain causes great losses such as weight loss, loss in nutritional value, and loss in seed viability. The most important insect pest which brings about these losses in stored cowpea is the cowpea weevil or bruchid, *Callosobruchus maculatus* (Schoonhoven, 1978; Mkenda and Ndakidemi, 2014) due to its feeding activities. The initial infestation begins in the field (Prevett, 1961), and in shelled seed, the pest multiplies rapidly in storage with a generation time of 3-4 weeks. Thus, losses tend to be greater when storage is going to last longer or in the marketing sector where mostly shelled grains are sold. Losses are less severe where farmers tend to store their cowpea seeds in the pod.

In Africa, research has found out that about 30% to 80% of the total cowpea production valued at over 300 million US dollars is either lost or suffers damage annually as a result of *C. maculatus* infestation (Mkenda and Ndakidemi, 2014). These losses caused by *C. maculatus* are estimated to be about 87% to 100% within storage period of 3 to 6 months. These losses results in both quantitative and qualitative reduction in value of the cowpea grains (Iloba *et al.*, 2007). These attributes of the insect pest infestation to yield and economic losses is 100% possible considering the beginning of its infestation, the developmental period and its population builds up in the store leading to these heavy losses (Iloba *et al.*, 2007; Soundararajan *et al.*, 2012 and Stejskal *et al.*, 2014).

The technology or methods adopted in storing cowpea grains is another major constraint especially among the rural poor farmers. Most of the resource poor farmers in the rural communities still adhere to their indigenous storage methods that are not effective in controlling the pest (Mahama, 2012). These farmers are either not exposed enough to the new technologies developed to control these pests or do not have financial support to enable them adopt these technologies. Air tight storage, solarization, use of botanicals and fumigant chemicals can provide control, but these are difficult to achieve in practice. Farmers in the rural communities need to undergo some training on the use of some of these technologies in order to effectively protect their cowpea grains against *C. maculatus* damage in the store. Also the search for new simple, less costly and effective technologies to control the insect pests from the field where it begins its infestation way up to the store will be highly useful. This will reduce or even eliminate the losses and enhance food security among the people (Mkenda and Ndakidemi, 2014).

h) Storage pests of cowpea

Storage pests are an important constraint to dry grain legumes in store worldwide. Rodent pests such as rats and mites feed on the grains in the store when measures are not taken to protect the store room against them. They also cause damage to storage systems and are vectors of various diseases that pose threats to human health. Fungal mold development on the grains is no exception especially, in instances where the grains are not dried to the required percentage moisture level that is safe for storage (Gomez, 2003). Mite species such as the flour mite, *Acarus* *siro* (Acari: Acaridae) may be important in some African countries (Bayih, 2014). However, these are minor pests on stored legume grains.

The major pests that cause economic losses to grain legumes are the storage insect pests. Some of these pest species include *Acanthoscelides* species, *Callosobruchus* species, and *Zabrotes* species, (Schoonhoven, 1978; Jones, 1999; Stejskal *et al.*, 2014). Jones (1999) reported that *Acanthoscelides* species and *Zabrotes* species are the two main storage pests of cowpea. Schoonhoven, (1978), however indicated that there are many other insect species found on the stored beans that are of minor importance. On the contrary, Keneni *et al.*, (2011) reported that *C. maculatus, C. chinensis, C. analis, A. obtectus, Bruchus incarnates, B. rufimanus, B. dentipes, B. quinqueguttatus, B. emarginatus, B. ervi, B. lentis and B. pisorum* are the most important species of storage insect pests that cause significant losses in food legumes including *Vigna* species.

Among these storage insect pests of cowpea, it is well established that *Callosobruchus* species is the most important pest due to its ability to infest the grains from the field (Stejskal *et al.*, 2014). *C. maculatus* is the outstanding one among the species due to the nature of its damage and economic losses it causes to grain legumes especially cowpea (*Vigna unguiculata*).

i) The family Bruchidae

There are several species of the Family Bruchidae that are known to attack different types of stored grains including cowpea. These insects spend almost their entire lives within a single grain. About 1,350 species of this family are reported worldwide (Tuda *et al.*, 2006; Fatimah *et al.*, 2016). Among these species, those with African host range are the most popular and important species with *Callosobruchus maculatus* being the most important one due to the damage it inflicts on cowpea grains (Beck and Blumer, 2014; Devi and Devi, 2014; Fatimah *et al.*, 2016).

Insects of this family are generally compact and oval in shape, with their heads hypognathous or opisthognathous; ocelli absent ant their eyes shallowly to deeply emarginated. The antenna is 11-segmented with insertion adjacent to the eye; mandibular apex acute, medial margin entire, not dentate; gular sutures short, ending in tentorial pits; fronto-clypeal suture well marked. Elytral striae are always present, usually 10 in number; metatibia usually longitudinally carinate; tarsal claws appendiculate; pygidium exposed beyond elytral apices. The male genitalia is with a base of median lobe and ventral strut of tegmen modified into a pump to avert internal sac during copulation. Lateral lobes (parameters) are always present (Kingsolver, 2004; Beck and Blumer, 2014). The male *C. maculatus* is about 3.21 mm long and 1.91 mm wide while the length of the female *C. maculatus* is 3.70 mm long and 2.17 mm wide (Devi and Devi, 2014). Adult females deposit their eggs on grains though initial infestation starts from the field on pods (Mkenda and Ndakidemi, 2014). The larvae subsequently chew their way into the inside of the grain after hatching.

Cowpea weevils are not true weevil in that; they lack the snout of a true weevil. The insect is more elongated in shape than other members of the leaf beetle family. It is reddish-brown overall, with black and gray elytra marked with two central black spots. Usually they appear brown in color often with mottled patterns. The last segment of the abdomen extends out from under the short elytra, and also has two black spots (Fatima *et al.*, 2016).

Table 1 below shows some of the species under this family however, the common and the most important species under the family bruchidae are those described further below (Devi and Devi, 2014; Fatima *et al.*, 2016).

Table 1. Bruchid species, their host plants and their natural range estimation.

Bruchid species	**Host plant**	**Natural range estimation**
Callosobruchus analis (Fabricius)	*Vigna radiata*	African and Asian
Callosobruchus chinensis (Linnaeus)	*Vigna angularis*	Asian
Callosobruchus dolichosi (Gyllenhal)	*Cajanus scarabaeoides*	Asian
Callosobruchus imitator (Kingsolver)	*Vigna umbellata*	Asian
Callosobruchus latealbus (Pic)	*Rhynchosia acuminatifolia*	Asian
Callosobruchus maculatus (Fabricius)	*Vigna unguiculata*	African
Callosobruchus nigripennis (Allard)	*Cajanus scarabaeoides*	Asian
Callosobruchus phaseoli (Gyllenhal)	*Lablab purpureus*	African
Callosobruchus pulcher (Pic)	*Cajanus cajan*	Asian
Callosobruchus rhodesianus (Pic)	*Vigna unguiculata*	African
Callosobruchus semigriseus (Motsch.)	*Dunbaria bella*	Asian
Callosobruchus subinnotatus (Pic)	*Vigna subterranea*	African
Callosobruchus theobromae (Linnaeus)	*Cajanus scarabaeoides*	Asian
Callosobruchus utidai (Tuda)	*Dunbara podocarpa*	Asian
Acanthoscelides obtectus (Say)	*Phaseolus vulgaris*	American
Zabrotes subfasciatus (Boheman)	*Phaseolus vulgaris*	American

***Callosobruchus maculatus* (Fabricius)**

Callosobruchus maculatus is the most common and distructive among the Family Bruchidae in the West African sub region. This species has inner carina of the hind femur smooth; their inner tooth typically longer than the outer tooth. The pronotum of the adult has black cuticle and golden setae with the exception of the basal median gibbosites, which extend well beyond the posterior margin that is covered with white scale-like setae. They have their eyes very deeply emarginate, prominent and bulbous. The male genitalia of these species are distinct, median lobed with two longitudinal sclerotized denticulate areas near its middle (Fatima *et al.*, 2016).

***Callosobruchus chinensis* (Linnaeus)**

Callosobruchus chinensis is next to *C. maculatus* in terms of abundance and damage to cowpeas at the storage level. The adult male of this species have their antennae pectinate with its segments 4-10 conspicuously expanded antero-laterally whereas the females have their antennae serrate. Usually, segments 4-11 of the antennae of both sexes appear dark brown (rarely yellowish-brown). The inner tooth of the hind femur appears with its sides more or less parallel, converging near the apex. The males have their genitalia with median lobe more elongate, apex with exophallic valve spearhead-shaped, and base with two sclerotized plates (Fatima *et al.*, 2016).

***Callosobruchus analis* (Fabricius)**

Callosobruchus analis is not common in Africa. This species have their inner carina of hind femur appearing numerous and irregularly-spaced small denticles along its proximal two-thirds. They have their inner tooth rather shorter than or equal to their outer tooth with their pronotum appearing with uniformly reddish-brown cuticle, and with sparse golden setae with the exception on the basal median gibbosites, which extend only slightly beyond the posterior margin with sparse white setae. Their eyes are less deeply emarginated but rather flattened and less prominent with the male genitalia having median lobe without sclerotized areas near its middle (Fatima *et al.*, 2016).

***Callosobruchus udemptus* (Pic.)**

Callosobruchus udemptus have their inner tooth of hind femur conspicuously longer than the short blunt outer tooth. The body cuticle of this species appears black, with a pattern of grey, black and brassy setae on the dorsum having a length 2.75-3.0 mm (Fatima *et al.*, 2016).

***Callosobruchus subinnotatus* (Pic.)**

The body cuticle of *Callosobruchus subinnotatus* is uniformly black or very dark brown with dark reddish highlights on legs and antennae occasionally. The setae of this species are grey or brown and never forming a distinct pattern on the elytra, but usually with a vague pattern of whitish setae on the elytra of females. The length of this insect is 4.0-5.5 mm. (Fatima *et al.*, 2016)

j) Origin and distribution of *C. maculatus*

Bean beetle, *Callosobruchus maculatus* (Coleoptera: Chrysomelidae: Bruchinae), is one of the most widespread species of bruchid distributed throughout the tropics and sub-tropics (CABI, 2014). It is a major agricultural insect pest of Africa and Asia. Information on its origin is not well known but, Decelle (1981) believed *C. maculatus* is native to Africa. Bruchids (*C. maculatus*) are found naturally on all major land masses except New Zealand and Antarctica. More intense speciation has occurred in the tropical regions than in the temperate, and fewer species are found in tropical rain forests than in more xeric regions (Kingsolver, 2004). Small isolated islands usually have little or no bruchid fauna because establishment of most bruchids depends on the previous invasion and establishment of suitable food plants for oviposition. The literature is scattered through a wide range of publications that are generally unavailable to most workers. Because many bruchids are critically important pests of stored legumes, their correct identification is vital to their effective control. The U.S. and Canadian literature was combed for data on classification, host plant associations, geographical distributions, and parasitoids for this compilation (Kingsolver, 2004). The insect presently has a wide range of coverage throughout the tropical and subtropical world (Beck and Blumer, 2014).

Callosobruchus maculatus (F) is believed to have originated from West Africa where cowpea is mainly produced (Mahama, 2012). It has a cosmopolitan distribution that makes it able to spread all over the continent with the movement of cowpea (Tran and Credland 1995). *C. maculatus* distribution is now worldwide, on legumes (pulses) both in store and in the field before harvest with harvesting time affecting its survival, multiplication and distribution (Baidoo *et al.*, 2010). It is a major insect pest of economically important leguminous grains, such as cowpeas, lentils, green gram, and black gram (Devi and Devi, 2014).

k) General biology of *C. maculatus*

Adults of *C. maculatus* are normally found in flowers in the early part of the season. They are seen colonizing cowpeas at the end of the rainy season carrying on with their population increase in the stores where they continue to develop and multiply (Gomez, 2004). Larvae typically feed inside the cowpea, taking from 2 to 6 weeks to develop before pupating in there. Six or seven generations may occur per year depending upon the environment and the resources available. Larvae chew near the surface and leave a thin covering uneaten which appears as a "window". Later the adult emerges from the "window".

The life cycle of *C. maculatus* according to Devi and Devi, (2014), consist of egg, four larval instars (L1, L2, L3 and L4), pupa and adult. The eggs hatched in about 6-7 days and the larval duration varied from 18-22 days. The typical period for each stage at 25 ^{o}C is as follows (Gomez, 2003): The eggs hatch in about 4 days time going through 4 larval instars that take 22 days. Pupation takes 3-4 days after the fourth larval instars stage resulting in a total development period of approximately 30 days. A single female adult bruchid is capable of laying up to 100 eggs under laboratory conditions in its life time by dispersing them on the grain (Beck and Blumer, 2007). In the store, *C. maculatus* completes its entire life cycle from eggs laying through larval development and pupation to emergence within a single grain (Mkenda and Ndakidemi, 2014). Although infestation of cowpea grain starts on the field, larval stage is the major destructive stage since the adult insects do not feed on the cowpea grain (Beck and Blumer, 2014) but rather possibly on nectar or polling grains (Kingsolver, 2004). The laid eggs on the cowpea grains hatch and each tiny grub-like larva after hatching bores through the bottom of its egg shell and in to the grain where it feeds grows and develops.

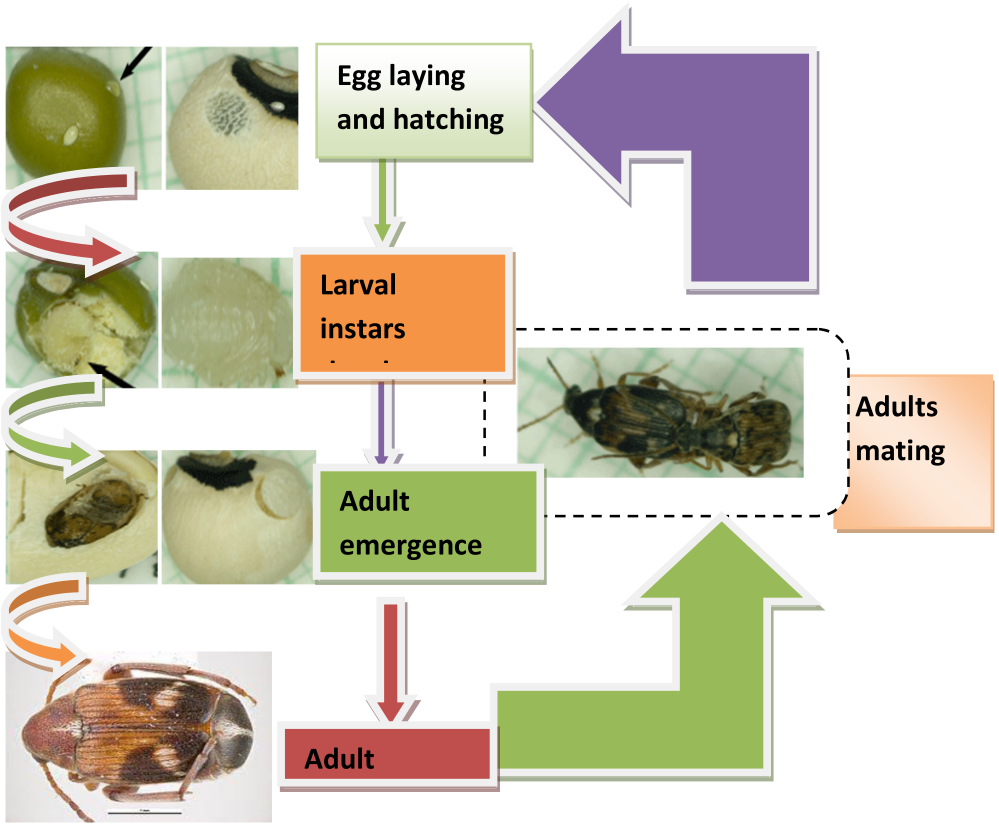

Figure 1. The generalized life circle of C. *maculatus*.

Adult sexes can readily be identified by means of readily observed morphological differences that are easily seen with the naked eye. The adult females have dark stripes on each side of their posterior dorsal abdomen that is not found in the male adults (Beck and Blumer, 2007, 2014). Males of bruchid are easily distinguished from the females because they are sexually dimorphic in nature. The females are sometimes broader and darker where as the males on the other hand, appear brown and this is noticeable on the plate covering the lower part of their abdomen (Beck and Blumer, 2014).

The adult bean beetles exist in two forms (morphs); a sedentary (flightless) form and a dispersal (flying) form. The dispersal (flying) form which is not common among stock cultures is induced by high larval density in stored beans or laboratory cultures. Usually, it is caused by microhabitat that is density dependent and rise in temperature (Beck and Blumer, 2014).

l) **Ecology and behavior of *C. maculatus***

Ecologically, the bean beetles are mainly plant eaters (herbivores). They are noted to have specialized on legume grain consumption. They are known for attacking the cowpea *Vigna unguiculata*, although they also readily attack other beans and peas such as the mung bean *Vigna radiata* and adzuki bean *Vigna angularis* (Beck and Blumer, 2014). The adult is more likely to seek the legume in which it developed as a larva and will only utilize another type that is less common as its food source if its host legume is unavailable (Messina, 2004). They form part of the food web since their eggs and larvae are preyed upon by some parasitoid wasp species. The adults may also be preyed upon by birds, reptiles and amphibians. By so doing, they do have the purpose of providing food for other organisms in the food chain (Beck and Blumer, 2014).

The female usually oviposits on the grain preferring the smooth side and will usually avoid grains lucking smooth surfaces (Cope and Fox, 2003). Based on the equal distribution of nutrients for the young larvae, the adult female has a way of distributing the eggs among small and large legumes such that each larva has access to roughly the same amount of nutrients.

The insect's assessment of the grain is based on mass and on the number of eggs already there on the grains rather than surface area (Cope and Fox, 2003). The larva will usually dig a cell considered as an exit hole in their feeding chamber (Fatimah *et al.*, 2016) within the bean and lines it with faeces when it is preparing to pupate. If it encounters another larva in the bean, both retreat and create walls of faeces and if by mistake the wall is removed, the two larvae will fight to their death, a behavior that is not well understood by many scientists (Mano and Toquenaga, 2008) but could be attributed to food security and conservation reasons (Johnson and Romero, 2004). The species suffer from inbreeding depression, but it does not seem to take behavioral action to avoid it (Fox and Reed, 2010, 2011). Inbreeding is more common in laboratory situations where the beetle is allowed to breed continuously with frequent supply of food. On the contrary, breeding on the field is more limited (Fox and Reed, 2010) since food source and time availability are both limited and can only support the development of one generation.

m)* Damage and economic impact of *C. maculatus

about 75% of world's cowpea production comes from Africa. These are however subjected to heavy losses or even an entire crop failure as a result of severe insect pest predation. Cowpea suffers terrible set backs from its natural enemies for which insect pests are the worst among these enemies (Gomez, 2004). In fact, some scientists are of the opinion that insect pests are the most important deteriorating agents that reduce cowpea and other legume species quality in stores. They estimated about 37% of cowpea and other leguminous crops lost to insect pests during storage for a period of nine months (Onyido *et al*., 2011).

Out of those insects that causes the post harvest loss, *Callosobruchus maculatus* (Fabricius) is observed to be the most important pest that mainly attack cowpea grains of many species, and can alternatively attack other leguminous crops such as *Vigna subterranean* (Bambara groundnuts) and *Cajanus cajan* (Pigeon pea). For this reason, this insect pest is regarded as being responsible for most of the losses that occur in stored bean seeds (Onyido *et al.*, 2011).

Callosobruchus maculatus alone can destroy a granary full of cowpeas within two to three months. Meanwhile, people need to have the grain for consumption throughout the year (Gomez, 2004). In effect, *C. maculatus* causes serious postharvest losses to most legume crops in both quality and quantity, particularly in the tropics and sub-tropics where temperatures and relative humidity are high (Keneni *et al.*, 2011).

Stored cowpea grains are considered the favorite food of this insect pest. The crop however, picks up its initial infestation from the field just before harvest (Prevett, 1961). The adults and larval insects are then carried into the store along with the grains where their population builds up rapidly (Mkenda and Ndakidemi, 2014).

They lay their eggs on the pods as the crop approaches maturity on the field and their emergence usually occurs after harvest. They emerge on the pods and burrow through the pods to the grains on which they continue their infestation at the store.

The damage to the cowpea grains is mainly caused by the larvae through their feeding activities. This feeding activities start from when the eggs hatch since the newly hatched larvae are hungry and will readily feed on any available food source. After hatching, the larvae bore through the grain and continue feeding internally.

The damages caused on cowpea by bruchids while on the field have been reported to have gone as high as 11% and capable of reaching 20% in the store with later developments (Qazi, 2007). Storage losses in West Africa are substantial in spite of the use of storage insecticides by merchants. This makes most West African farmers sell their cowpea grains shortly after harvest since they do not want to deal with the storage problems.

In Ghana, research conducted during the storage season in 96-97 recorded the damage on stored cowpea grains in the Northern Region as high as 50%. This brings about decrease in the number of farmers who store their grains over the entire storage season. Other farmers sell or consumed their cowpea leaving the very few farmers who kept their cowpea in store over the entire storage season (Gomez, 2004).

Food quality is very important in developing countries like Ghana, where grain legumes are the major source of high protein foods for the majority of the population. Post harvest infestations at the store result in huge loses of both quantity and quality of the stored commodities. These are noticeable in the changes of the grain coat texture, grain color, taste, reduction in nutritional values, appearance, and the acceptability at the market level (Qazi, 2007). These damages or postharvest losses caused to stored products take place at different levels of their storage. These start from the production levels through to the market and the central store levels with different magnitudes (Onyido *et al.*, 2011).

These damages at the different levels in effect, are what reduce the quality of the crops, hence affecting its market value, change the taste of the crops and also pose threat to human health when these insect pests are consumed along side with the food (Onyido *et al.*, 2011). Secondary re-infestation of grain legumes by storage pests affects not just farmers but post-harvest traders and ultimately consumers as well since the infestation reduces the market and nutritional quality of the grain (Ahmed, 1983). The seeds of legumes, once badly damaged by storage insects, are no longer fit for planting and consumption due to poor germination and spoilage or bad smell respectively.

The magnitude of damage and yield loss caused by the insect depends on the number of eggs it lays on the grain and their ability to hatch (Ahmed, 1983). Each egg laid when hatched, leaves behind a hole or perforation that is covered by a thin lining of the egg on the seed coat filled with frust. This frust in addition to the seed coat is finally pushed out when the insect emerges as matured adult after pupation (Beck and Blumer, 2014). The perforations are used as an indication or index for damage and post harvest loss. Perforations caused by *C. maculatus* reduce the quality, quantity and germination percentage of the grain. *C. maculatus* has the ability to multiply very fast in the store on the cowpea grains and will be able to have several generations within the storage period of the grain due to its short life cycle (30 days) coupled with its ability to withstand a high degree of inbreeding (Ahmed, 1983). This behavior confirmed it as being the most damaging post harvest insect pest on cowpea.

Losses as low as 20% to as high as 50% may sometimes be encountered in some of the important legumes such as faba bean, field pea, chickpea and lentil from some belligerent storage insect pests like *C. chinensis* (Ali and Habtewold, 1993 and Damte and Dawd, 2003). Losses as as high as 50% to 100% have been reported on cowpea as a result of the damage caused by *C. maculatus*. Even with only a small amount of actual biological losses, economic losses can be as high as 100% (Boeke *et al.*, 2004 and Somta *et al.*, 2006).

The seeds of legumes, once damaged by storage insects, are no longer fit for planting (due to poor germination), for food or feed (due to spoilage and bad smell) (Aslam *et al.*, 2006; Haile, 2006). Irrespective of the importance of storing seeds as a strategy of stabilizing market prices between supply and demand (CIAT, 1986), the damages caused by the pests on cowpea, particularly under subsistence farmers' conditions, impeaches the maximum use of the market opportunities (Ali and Habtewold, 1993; Damte and Dawd, 2003). The remaining value chain actors of cowpea such as traders, food processors, and consumers also lose from storage pest damage (Keneni *et al.*, 2011).

n) Management strategies for *C. maculatus*

Control of the pulse beetle *C. maculatus* (F.) is crucial if increase in yield and quality of the cowpea grains at storage are to be improved. Fortunately, there exist several management strategies for *C. maculatus* (F.) in cowpea at both field and storage (Oyewale and Bamaiyi, 2013). Discussed below are the few important control measures of the cowpea weevil in stored cowpea.

i) Monitoring

Pest monitoring is an important component in IPM postharvest practice for stored grain (Shankar and Abrol, 2012). Inspections should be done frequently, especially after first storage, in order to make sound pest management decisions (Subramanyam and Hagstrum, 1995). Population density estimates and estimation methods as was stated by Shankar and Abrol (2012) included the following techniques: (i) absolute estimates (e.g. number of insects per kilogram of grain or number of moths per square metre); (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.). Trapping relies on insect 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. Traps recover insects from a much larger volume of grain than direct sampling.

Sampling should be performed at periodic intervals (sequential sampling) to gather information about population changes over time (Shankar and Abrol, 2012). According to Shankar and Abrol (2012), sampling should be performed monthly for grains stored above 20^{o}C, but longer than a month for grains held below 20^{o}C sampling intervals. Selecting sampling frequency can also be based on the time taken for the insects to complete one life cycle. Should insect populations exceed an economic threshold, fumigant application is recommended. However, in this contemporary era, little information is available concerning the economic thresholds at which fumigants should be administered in stored grain to achieve effective control of insect pests. Monitoring of insect populations and quality deterioration over a particular period of time will thus be an important technique in determining economic thresholds in storage (Shankar and Abrol, 2012).

Monitoring for *C. maculatus* infestation requires skills. Based on this, only the trained farmers who know the insect pest can undertake this exercise. However, other farmers can also do field scouting in their own fields at regular intervals to monitor the major pest situation. Surveillance on pest occurrence in the main field should commence at the physiological maturity stage of the cowpea crop and at weekly intervals thereafter. In each of the fields, five spots are randomly selected. Then again select five plants randomly at each spot for recording counts of pods and seeds showing sign of bruchid damages as per procedure finalized for individual insects.

When it comes to sampling in the store grains, samples of the grains are fetched from the top middle and bottom of the storage material containing the grain to represent the whole grains. This can be done as many times as the storage period will last at reasonable interval set for the insect based on its life cycle. In the case of *C. maculatus*, one sample every week will cover the entire life cycle of the insect using only four samples since the insect life cycle takes about 30 days to complete (Beck and Blumer, 2007, 2014; Mkenda and Ndakidemi, 2014).

ii) Physical control

Physical control is a simpler method of pest contro1 that may be effective with only a few insect species. It involves physical destruction of the pests by hand picking and destroying all forms of the insect (eggs larvae and adults). Physical control also involves sorting the grains into good and bad ones and picking out the insects if they are present, or their eggs if noticed. For example cowpea weevil adults and eggs found in the grain can be handpicked and destroyed before and during storage (IITA, 1982).

Temperature regulation is another physical control method that plays a very crucial role in *C. maculatus* survival and development since all insects have their thermal death points; a temperature at which they are unable to survive (Murdock *et al.*, 2003) due to their limited physiological capacity to thermo regulate at high temperatures (Maina and Lale, 2004). Temperature management is now seen to be one of the most promising methods used for controlling pests of stored grain as it offers a way to disinfest beans (Yamane, 2013). Although temperature control offers a way to disinfest beans, there is the potential problem of the effect of the treatment on the beans and the cost of the equipment to be used for the control. For this reason, further research on the effects of temperature, especially high temperature, and low cost equipments are needed (Yamane, 2013).

With regards to the cowpea weevil, Murdock and Shade (1991) documented the inability of all the life stages of the insect (egg, larvae, pupa and adult) to survive when exposed to 57^{o}C for 1 hour. This is due to the fact that they do not thermo regulate in addition to their immobility. They are unable to escape from the hot environment. Furthermore, eggs deposited on the surface of the grains when exposed to high temperature and low humidity conditions, dry out (Maina and Lale, 2004). For that matter, bruchids living within cowpea grains are excellent targets for management using elevated temperatures (Murdock *et al.*, 2003).

Murdock and Shade (1991) also explained that the use of plastic sheeting to enclose the cowpea grains and heating them helps greatly in achieving the required temperature to kill all the insects in the cowpea grains, and thus able to disinfest the grains. This, they explained, was realized by putting up a simple experiment in which black plastic sheeting was laid on the ground, and then covered to a depth of 1-2 cm with infested cowpea grains. A second, translucent plastic sheet was used to cover the grain on the lower sheet, and then the edges of the two plastic sheets were sealed by folding the upper sheet under the lower one and securing the envelope so formed with small stones laid around the edges. When this was exposed to the sunlight, the temperature within the envelope rises rapidly due to the solar energy that passes through the translucent upper sheet and being absorbed by the cowpea grain and the underlying black plastic sheet.

Within 15 -30 minutes the temperature within the cowpea grain typically rises to 60 – 70^{o}C, more than adequate to kill all live stages of the cowpea weevil.

iii) Mechanical control

Mechanical control involves the use of devices, machines and other mechanical devices to control pests or alter their environment. Traps, screens, barriers, fences and nets are example of devices used to prevent bruchid activities or remove them from an area. Cold or heat to kill insects or slow down their activities, screens to keep insects out and others that attracts and kill insects, are not very effective for field crop pest but are widely used against insect pest of stored grains.

Hermetic storage bags which reduce internal oxygen levels, increase *C. maculatus* mortality and reduce the invasion from outside when used to store cowpea is now widely recommended (PICS, 2015; Yamane, 2013). Exclusion, one of the reliable mechanical control techniques involves using barriers to prevent pest from getting into an area. Window screens for instance, will exclude the flying forms of the insect. Sealing or patching cracks, openings and other crevices in the store can exclude the insect coming from an infested store.

Studies carried out by Bean cowpea CRSP scientist on feasibility of metal drum storage compared with botanicals, steam treatment and other storage technologies for rural and urban use indicated that drum storage has the greatest economic advantage for a storage periods of 3 months and above (Lowenberg-DeBoer, 1998). It has lower labor requirement than solar treatment or insecticides because the grain is handled only to fill and empty the drum. For solar or insecticide treatment, the grain must be handled with an additional time to be more effective providing an additional cost (Gomez, 2003). The use of botanicals would also add mainly to the labor cost of drum storage because of the time required to find and prepare the appropriate plant materials.

In some parts of Africa such as Senegal, drum storage is economical because of the large supply and hence modest cost of steel drums (Gomez, 2003). Unlike other regions, drums are often sold at higher prices and drum storage may be less economical than triple bagging, botanical treatments, solar treatment or other storage technologies.

iv) Cultural control

The goal of cultural control is to alter the environment, the condition of the host, or the behavior of the pest to prevent or suppress infestations. It disrupts the normal relationship between the pest and the host and makes the pest less likely to survive, grow or reproduce. Cultural control involves preventing the grains from all the practices that seeks to attract or leads the grains to insect pest infestations. This method requires a certain cultural practices that may allow the grains to escape the pest damage (IITA, 1982). Such practices could involve storing the grain where there is inactivity of the pest. An example is keeping the stores free from an infested stock to avoid pest infestation.

Store hygiene and sanitation are the two main examples of cultural control. Many cultural practices influence the survival of pests. Cultural practices in crop fields such as the timing of planting and harvesting for instance can influence the infestation of bruchids from the field (Prevett, 1961; Partnaik *et al.*, 1986; Baidoo *et al.*, 2010). Intercropping the cowpea crop with cereals such as maize on the field with timely harvesting significantly reduces the most important species of bruchids infestation on cowpea in many parts of Africa (Olubayo and Port, 1997; Baidoo *et al.*, 2010). Planting date is an important cultural practice that was also reported to have significantly influenced the infestation levels of these insects on the fields (Patnaik *et al.*, 1986).

In order to escape pest damage, only well dried and uninfested grains should be stored. This can be achieved by separating the infested ones from the uninfested ones by harvesting non infested pods separately from already infested pods. After harvest, it is still prudent to make sure that the pods are well dried at a very safe place out of already infested produce to prevent infestation from them. After threshing, the grains have to be winnowed properly making sure that they are not stored with unwanted materials.

Cultural control measures for bruchids control under smallholder conditions mainly depend on storage conditions. Only adequately dry and properly cleaned seeds should be stored. The stores must also be free from bruchid infestation and should be well ventilated to discourage pest invasion and establishment (Bayih, 2014).

v) Biological control

Biological control involves the use of natural enemies or predators to control insect pests (Singh and Das, 2016). Biological control of pulse beetle population and their damage to stored grains is an important alternative to the use of synthetic chemicals in controlling the insect (Amevoin *et al.*, 2007; Iloba *et al.*, 2007; Soundararajan *et al.*, 2012). It also represents an interesting alternative for low income small-scale producers in West Africa (Huis, 1991) due to its cost effectiveness. Biological control using natural predators and parasitoids is cost effective and does not need so much income to achieve.

This identification has therefore triggered studies on the insect population dynamics on cowpea in field and granaries. This has lead to the identification of a solitary ecto-parasitoid of larvae and nymphs of Bruchidae and *Dinarmus basilis* Rond (Hymenoptera: Pteromalidae) (Iloba *et al.*, 2007; Effowe *et al.*, 2010; Soundararajan *et al.*, 2012). Parasitoids such as *Eupelmus vuilletii* (Crawford) (Hymenoptera: Eupelmidae), *Uscana lariophaga* Steffan (Hymenoptera: Trichogrammatidae) and *Dinarmus basalis* (Rondani) (Hymenoptera: Pteromalidae) are examples of those that parasitizes beetles on grain legumes (Yamane, 2013). Of these, *Dinarmus basalis* (Rondani) (Hymenoptera: Pteromalidae) is the most common one known. It parasitizes late-instar larvae and pupae of a wide range of beetle species, having a stronger impact on beetle populations than the other species (Monge *et al.*, 1995; Jaloux *et al.*, 2004). The release of *D. basalis* adults in suitable numbers and under suitable conditions reduced populations of *C. maculatus* drastically and halted seed weight loss for 6-7 months in West Africa (Sanon *et al.*, 1998; Ouedraogo *et al.*, 1996; Amevoin *et al.*, 2007). Studies carried out under different experimental conditions in different climatic zones of West Africa showed that introduction of *Dinarmus basalis* adults in to store houses at the beginning of storage could effectively control bruchid populations (Singh and Das, 2016) and preserve good quality seeds after 6 months of storage (Glitho *et al.*, 1998; Dugravot, 2002; Amevoin *et al.*, 2007; Soundararajan *et al.*, 2012). Iloba *et al.* (2007) reported that *Dinarmus basalis* is an efficient natural enemy capable of being used as a biological control agent leading to about 80 to 90% control of bruchids in the field and in the store.

Yamane (2013) also reported several natural parasitoids that are able to control the beetle at all its developmental levels. Females of the wasps oviposit on the eggs, larvae, or pupae of *C. maculatus* and the emerged larvae of the wasps feed on them. Under natural conditions of infestation of cowpea grains in the field, the numbers of this natural enemies are low and do not provide an effective control of the beetle population (Amevoin *et al.*, 2007).

These parasitoids need suitable temperature and humidity to be effective as biological control agents. And within closed storage systems, populations of both hosts and parasitoids can reach high densities, which could lead to high intra-and inter-specific competition among parasitoids for the host resource (Yamane, 2013). An example is among *E. vuilletii* females (Mohamad *et al.*, 2010) and between *E. vuilletii* and *D. basalis* (Monge *et al.*, 1995; Jaloux *et al.*, 2004; Mohamad *et al.*, 2011). Such competition may reduce the parasitoids' effectiveness at biological control, though the coexistence of *U. lariophaga* did not change the ability of *D. basalis* to suppress *C. maculatus* population and their damage to beans (van Huis *et al.*, 2002). Before parasitoids are used as biological control agents, it is necessary to take into account the costs and benefits associated with the optimum environmental conditions, numbers, kinds, and combination of parasitoid species (Yamane, 2013).

vi) Use of synthetic insecticides

Chemical insecticides have been employed in the control of bruchid pests. They often proved to be very effective in controlling these pests in store (Mkenda and Ndakidemi, 2014). They provide a very quick and almost 100% control. Chemical control of weevils is readily obtained with several products and is one of the most widely control tactic used in storing cowpea (Mahama, 2012; Mkenda and Ndakidemi, 2014). Synthetic insecticides, such as malathion, aluminium phosphide, pirimiphos-methyl, dichlorvos (dichlorovinyl dimethyl phosphate-DDVP), deltamethrin, cypermethrin and carbaryl, among others, are being used for controlling stored product pests either as fumigants or contact insecticides (Olajire *et al.*, 2016). Based on the intended use of the pesticide, they may be applied in a form of powder as in the case of Actellic super dust (Pirimiphos-methyl), liquid formulation as in the case of Karate or fumigant/gas formulation as in the case of phoxtoxin (Schoonhoven, 1978; Mkenda and Ndakidemi, 2014).

In order to preserve significant quantities of cowpea, farmers have turned to the use of synthetic insecticides, majority of which are not intended for Bruchidae (Mahama, 2012). Synthetic insecticides such as organophosphates are important and effective tools in modern stored product pest management. However, these pose serious threats to the environment, human beings and other warm blooded animals and eco-beneficial organisms when they come in to contact with these dangerous pesticides on food, in water and in the air around the produce (Sarwar, 2015). People often develop problems after consuming the insecticide treated produce especially when it is stored for a short period after treatment. When this happens, the grains then become unfit for human consumption.

Sarwar (2015) reported that almost ninety eight percent (98%) of sprayed pesticides do not reach their target pests and for that matter penetrate to the ground water, pollute streams and harm wildlife. It also harms the natural predators of the targeted pests within the vicinity of the targeted crop. It is undoubtedly clear that the misuse of these insecticides inevitably have harmful consequences on the health of the users, the consumers and the environment due to their indiscriminate usage especially by the local farmers and marketers. Many resource poor farmers usually lack adequate technical knowledge related to the safe use of these chemicals (Schoonhoven, 1978; Effowe *et al.*, 2010; Radha and Susheela, 2014).

In addition, continuous and widespread use of synthetic chemical insecticides may lead to serious problems such as development of resistance by the pest (Swella and Mushobozy, 2007; Effowe *et al.*, 2010) and an increase in the possibilities of pest resurgence, and lethal effect to the non-target organisms in the agro-ecosystems (Talukder, 2009). This leads to reduced effectiveness of control by the natural enemies and therefore favoring the development of the pest within the agro-ecosystem (Dugravot *et al.*, 2002).

Synthetic insecticide control measures have been difficult to be employed by majority of the small holder farmers. These farmers have insufficient income to enable them buy synthetic pesticides. This is due to the expensive nature of the pesticides, thus making the farmers revert or tend to rely on a variety of pesticidal plants and other natural products. Products such as plant extracts, powders, ashes, cow dung and oils to control the pests with varying level of effectiveness (Mkenda and Ndakidemi, 2014; Radha and Susheela, 2014). In addition, pesticides of the chemical origin can affect human health directly or indirectly by disrupting ecological systems that exist in rivers, lakes, oceans, streams, wetlands, forests and fields (Mkenda and Ndakidemi, 2014).

In a nutshell, the world wide ecology is being threatened from severe use of pesticides making the search for ecologically safe methods to control insect pests of field crops and stored food products an inspiring field of research (Reuben *et al.*, 2006; Sarwar and Sattar, 2012; Hina *et al.*, 2015). Ecological problems such as bio-magnification, resurgence and the development of insecticide tolerant strains of pest species come with the misuse of the synthetic chemical insecticides under storage conditions (Talukder, 2009; Radha and Susheela, 2014). Synthetic chemical control is therefore hazardous, since it poses a lot of threats to the lives of humans and other animals (Mkenda and Ndakidemi, 2014; Sawar, 2015). Phostoxin for instance can kill humans and animals (Ntoukam *et al.*, 2000) when exposed to it for a short time.

There is therefore an increasing interest in the use of plant based bio-pesticides in order to reduce the problems of environmental pollution, killing of non-target species and health risks to humans, as well as reducing the cost involved in purchasing synthetic chemical pesticides (Mkenda and Ndakidemi, 2014) hence the need to minimize or even eliminate the use of harmful synthetic chemicals.

Fumigation, another chemical control method is the method used in which insect pests are exposed to a poisonous gaseous environment, produced by applying fumigant considered to be effective method in which insect pests are controlled (Upadhyay and Ahmad, 2011). This is achieved by using phostoxin tablet at the rate of 1 – 2 tablets/100kg of seeds wrapped in a piece of cloth or tissue paper or perforated envelope and placing it within the grains inside the container with the grains (Allahvaisi *et al.*, 2010). For fumigation to be effective, the storage container or material has to be well sealed and the grain temperature, well recorded above 50 degree Farrahiet (Upadhyay and Ahmad, 2011).

In the case of cowpea grain storage, jute sacks or poly propylene bags with polythene inner liner or containers without leakage are used so as to make the storage effective. Since phosphine is characterized as a slow acting fumigant to which insects can develop resistance, an imperfect fumigation will increase the chances of the pests to develop resistance (Allahvaisi *et al.*, 2010). Although Phosphine is readily available and cheap, it is too toxic to recommend for farmers to use (Golob *et al.*, 1999). So do other synthetic insecticides that are used as fumigants to control stored insect pest in commercial centers which are costly and unavailable leading to their limited usage by the resource poor subsistence farmers (Dugravot *et al.*, 2002).

vii) Use of botanicals

Insecticidal plants are naturally occurring chemical insecticides (insect toxins) extracted or derived from plants and have been formulated specifically for their ability to control insect pests (Sarwar, 2015). Of late, measures to control insect pest infestations in stored products such as grain legumes and dry food products rely heavily upon the use of synthetic insecticides both gaseous and liquid. This poses health hazards to warm-blooded animals and a risk of environmental contamination (Mogbo *et al.*, 2014; Radha and Susheela, 2014). One alternative to the use of the dangerous expensive, toxic and environmentally unsafe synthetic insecticides is the use of insecticidal plants materials that are inexpensive, safe to the environment, users and consumers alike (Mogbo *et al.*, 2014). These products are commonly available to the resource poor farmer.

The use of these plant products assumed significance as an important component of insect pest management because of their economic viability and eco-friendly nature (Radha and Susheela, 2014). They have proved to be promising alternatives to synthetic chemical insecticides in reducing pesticide hazards in the environment. In recent times, an approach that would rely on the use of plant products (without involving synthetic pesticides) appears to hold the greatest hope for increased cowpea production in the traditional cereal–dominated cropping system throughout the tropics and sub–tropics (Yussuf *et al.*, 2011).

Sarwar (2015) reported the degrading of botanical insecticides readily in sunlight, air, and moisture, breaking down into less toxic or nontoxic compounds and posing less risk to non-target organisms hence their environmental friendliness.

Botanicals are generally short-lived in the environment and thus provide pest control for very short time (few days) (Ahmad *et al.*, 2011; Sarwar, 2015). For botanical insecticides, the earlier scientists have reported the development of inhibitory action and reproductive sterility effects against insects on stored product that are under constant attack by these pests. These attacks by the pest allow the products to making good use of their insecticidal properties essential to reduce the losses caused by the insect pests (Sarwar, 2015).

Several plant products have been reported to have played crucial role in controlling the insect pests on crop plants in the field (Olaitan and Abiodun, 2011; Mochiah *et al.*, 2011). These products also protect cowpea grains against insect pests at storage with varying rates of control (Ahmed *et al.*, 2014; Tiroesele *et al.*, 2015; Longe, 2016; Ojebode *et al.*, 2016; Ahmady *et al.*, 2017).

Brisibe *et al.*, (2011) reported that when neem is used in combination with other botanicals, it enhances its performance for both adult bruchid control and a lower weevil perforation index than when the grains are treated with 100% of either of the botanical insecticides used for the control.

Using different plant powders and rates, Yussif *et al.* (2011) also reported the performance of *Khaya senegalensis* (Desv.) A. Juss. (Mahogany wood ash) to be superior at all the different rates but not significantly different from *Zingiber officinale* Rosc. (Ginger powder) and Primiphos Methyle in reducing seed weight loss hence, the reduction in development of bruchids and their damage on cowpea grains.

Ahmed *et al.* (2014) conducted an experiment using synthetic insecticide (Actellic supper) and neem seed extract in managing storage bruchid in cowpea and observed no significant difference between the two. They therefore concluded that the botanical insecticide should be preferred based on benefit-cost analysis. The fact that the botanical insecticide was readily available, cheap, and friendly to the environment, not toxic to the farmer and livestock, and ease of application further explains its choice over the synthetic insecticide. Radha and Susheela (2014) also confirmed the effectiveness of the neem seed extracts in controlling bruchid when mixed with other botanicals.

Wahedi *et al.*, (2013) revealed that treating cowpea with neem seed powder, neem seed aqueous extract and neem seed oil prevented the emergence of *C. maculatus* as well as their feeding activities on cowpea grains. Therefore, the long term use of neem seed products that is available in Northern Region of Ghana will be viable. Its biodegradability, low cost, and ease of application will enhance cowpea production in this part of the country.

Ojebode *et al.*, (2016) uses extracts from lemon grass, orange peels and neem leaves in their experiment to control the pest and concluded that the essential oils of lemon grass and orange peels could be used in the integrated management of insect pest of cowpea grains in storage. Also, the fixed oil of orange peels and neem can be used for the same purpose but the efficacy of the essential oils is higher compared to the fixed oils. These could serve as an alternative to the synthetic chemicals used in insect pest control in storage to prevent the health and the environmental risks of these synthetic chemicals.

viii) Host plant resistance

The use of resistant varieties is sustainable and does not have long term undesirable impact on the environment and as such proven to be one of the best ways of controlling bruchid pest in store (Tembo *et al.*, 2016). In order to reduce over-reliance on synthetic pesticides for the management of cowpea weevil in Ghana, research on host plant resistance has to be developed (Ahmed and Yusuf, 2007). Fortunately, there is that potential of breeding cowpea for resistance to storage insect pests such as *C. maculatus* as there exist numerous potential resistant cowpea varieties and cowpea breeders (Tembo *et al.*, 2016; Kosini and Nukenine, 2017).

Research conducted in some parts of the world including Ghana documented different varieties of cowpea exhibiting different levels of susceptibility and resistance to *C. maculatus* (Edde and Amatobi, 2000; Obopile *et al.*, 2011 and Badii *et al.*, 2013). These will possibly provide genetic sources for cowpea breeding programmes. Resistance is an inherited dominant gene that can be rapidly back crossed into local varieties or other improved varieties when identified in promising resistant varieties (Jones, 1999; Obopile *et al.*, 2011; Badii *et al.*, 2013B; Kosini and Nukenine, 2017).

The identification of legume crops for resistance to storage bruchid pests is likely to be successful. Available studies demonstrated the existence of genetic variation in landraces, cultivated varieties and their wild relatives (Ahmed and Yusuf, 2007). An example is an evaluation of a core collection of *Vigna* species which showed a high level of bruchid resistance. This was reported by some scientists and may be considered to be potentially the most useful report since many of the cultivated accessions showed complete resistance to the insect (Keneni *et al.*, 2011). This was probably due to their very outstanding toxic nature to *C. maculatus* larvae (Beck and Blumer, 2007) making them unable to support normal development and the successful emergence of adults after oviposition.

Legume crops adopt different ways including direct and indirect defense mechanisms comprising of morphological barriers, secondary metabolites and anti-nutritional compounds (Ahmed and Yusuf, 2007 and Kosini and Nukenine, 2017).

Resistance is believed to be controlled mostly by a single or a few genes in many legume crops and transferring such resistant genes to commercial cultivars would be possible with conventional breeding approaches (Keneni *et al.*, 2011). Keneni *et al.* (2011) further documented that a number of specific insect resistance mechanisms have been identified in legumes although they have not yet been widely integrated into mainstream breeding programs.

Insect pest resistance in crops generally comprises of four mechanisms; anti-xenosis, antibiosis, tolerance, and escape. Tolerance and escape are resistance mechanisms relevant for field infestations where as anti-xenosis and antibiosis are resistance mechanisms relevant for storage insect pests of grain crops. It is undoubtedly clear that the processes of resistance involve morphological, physiological and biochemical mechanisms which encompasses simply minimizing the effect of insect attack to adversely retarding the insects' cellular processes, growth and development (Badii *et al.*, 3013A). Antibiosis expressed with the adverse effects upon larvae of bruchids feeding on the grains of a resistant host plant may also involve morphological, physiological and biochemical features. It may also involve the combination of these that may lead to the death of the insect pest (Keneni *et al.*, 2011).

There has been an indication from genetic improvements in some legumes for resistance to storage bruchid pests especially with the efforts made by some of the international research institutions. The International Center for Tropical Agriculture (CIAT) for instance serves as an example. It developed a series of haricot bean genotypes with arcelin-based resistance to *Zabrotes subfasciatus* whose initial gene source was from a wild accession. The International Institute of Tropical Agriculture (IITA) is another research institute that has also developed a number of cowpea genotypes conferring trypsin-based resistance to *C. maculatus* with the gene source accession being cultivated species (Keneni *et al.*, 2011).

Evidence from literature suggesting that some cowpea varieties are susceptible to *C. maculatus* in storage is true. Musa and Adeboye (2017) for instance, evaluated a number of cowpea varieties and came out with moderately resistant varieties which they recommended to be included in breeding programmes. In Ghana, Badii *et al.* (2013B) in an effort to reduce both seed loss due to bruchid attack and over-dependence on chemicals for *C. maculatus* control came out with promising resistant lines. They recommended these lines for inclusion in the CSIR-SARI cowpea breeding programme. CSIR-SARI subsequently used these lines in their crosses with other lines where in new and improved varieties were released

(CCVRRG, 2015). Yield and other agronomic traits of these varieties were emphasized. However, the resistance levels of these released varieties to the damage caused by *C. maculatus* are yet to be confirmed.

ix) Integrated control

Integrated management control is by far the most effective control tactics used in bruchid pest management. This involves the combined used of physical control, cultural management, mechanical control and biological control. Integrated management seeks to reduce or eliminate the use of synthetic chemicals due to the health and environmental hazards it poses. Integrated management even recently shifts towards using plant based insecticide otherwise known as botanicals in place of the synthetic insecticides that is currently being used widely.

For the past few years, different methods of controlling this bruchid have been employed. Notably among which includes treating grains with synthetic insecticides, fumigation with phoxtoxin and the use of botanicals to protect cowpeas from damaging stored grains. Other products such as ashes, sand and leaves of some plants are also used locally. Oil and powder obtainable from neem seed reported to have provided sustained protection of the stored grains (Maina and Lale, 2004) are now being promoted due to their effectiveness in controlling insect pests in stored grain legumes.

The use of synthetic insecticides to protect grains from bruchids is seen to be effective, but these chemicals are too costly and pose serious health hazards to farmers, traders and consumers as a result of its environmental pollution, contamination of the water bodies, grain contamination and toxicities. Furthermore, insects develop resistance to insecticides, necessitating the application of larger amounts leading to over dosages which brings about almost all the problems associated with the use of these chemicals. These problems can alternatively be reduced or even eliminated through the use of integrated management methods (Yamane, 2013). It is undoubtedly clear that combination of the different control methods otherwise termed as the integrated management will be the best approach in controlling the insect pest in cowpea grain protection.

CHAPTER THREE

3.0 MATERIALS AND METHODS

a) Experimental site

The study was conducted in the Entomology Laboratory of the CSIR-Savannah Agricultural Research Institute (SARI), Nyankpala, Northern Region, of Ghana, in 2017. The shelves and trays were cleaned and disinfested with a sterilizer (Sodium hypochlorite) for the experimental materials to be placed on them. Each tray took a set of all treatments making a replicate. Thus, four (4) trays were used for four replications. The bases of the trays and benches were painted with liquid oil to prevent crawling and predatory insects from climbing on to the set up and devouring the experimental insects. Temperature and re lative humidity were regulated.

b) Cowpea varieties

Seven cowpea varieties were used for the study, they varieties were Padi-tuya, Songotra, Apagbaala, Zaayura, Bawutawuta, Marfo-tuya and a local variety as a check. The first six varieties were obtained from the cowpea breeding programme of CSIR-SARI in Nyankpala while the local variety was obtained from a farmer at Kpalsogu in the Tolon District. Detailed morphological description of the test varieties are provided below.

Padi-tuya: This variety originated from IITA, Ibadan. It was released in 2008 and registered in 2015 with a national code of GH/Vu/005/15 by I.D.K. Atokple and Francis Padi of CSIR-SARI. The seed is round to kidney in shape with white seed coat and black helium colour. It matures in 64-67 days with a 100 seed weight of 22.0g. Padi-tuya is moderately resistant to field insects, diseases and striga. Padituya does well in Sahel, Sudan, Guinea savanna zones and humid areas.

Songotra: Songotra also originated from IITA, Ibadan. It was also released in 2008 and registered in 2015 with a national code of GH/Vu/006/15 by I.D.K. Atokple and Francis Padi of CSIR-SARI. The seed is fairly round in shape with creamy white seed coat and black helium colour. It matures in 62-65 days with a 100 seed weight of 15.0g. Songotra is highly resistant to striga. It is moderately resistant to most field insects and diseases but susceptible to aphids. Songotra does well in Sahel, Sudan, Savanna zones.

Apaagbala: Apagbaala also originated from IITA, Ibadan. It was released in 2004 and registered in 2015 with a national code of GH/Vu/004/15 by K.O. Marfo, Francis Padi and I.D.K. Atokple of CSIR-SARI. The seed is round to kidney in shape with white seed coat and black helium colour. Early maturing (60 days after planting). It is susceptible to striga and aphids and does well in Sahel, Sudan and Guinea savanna zones.

Zaayura: This variety also originated from IITA, Ibadan. It was also released in 2008 and registered in 2015 with a national code of GH/Vu/008/15 by N. N Denwa of CSIR-SARI. The seed is fairly round in shape with creamy white seed coat and brown helium colour. It matures in 64-67 days with a 100 seed weight of 22.50g. Zaayura is highly resistant to aphids but moderately resistant to other field insects, diseases and striga. Zaayura does well in Sahel, Sudan, and Guinea savanna zones.

Bawutawuta: This variety also originated from IITA, Ibadan. It was also released in 2008 and registered in 2015 with a national code of GH/Vu/007/15 by I.D.K. Atokple and Francis Padi of CSIR-SARI. The seed is fairly round in shape with creamy, dull luster seed coat and brown helium colour. Bawutawuta matures in 69-75 days with a 100 seed weight of 14.8g. Bawutawuta is highly resistant to striga, moderately resistant to some field insects and diseases but susceptible to aphids. Bawutawuta does well in Sahel, Sudan and Guinea savanna zones.

Marfo-tuya: This variety originated from IITA, Ibadan. It was released in 2004 and registered in 2015 with a national code of GH/Vu/003/15 by K. O. Marfo, Francis Padi and I.D.K. Atokple of CSIR-SARI. The seed is round to kidney in shape. The seed coat is dull cream luster with brown helium colour. It matures in 66-70 days after planting with a 100 seed weight of 17.0g. Marfo-tuya does well in Sudan and Guinea savanna zones.

Local variety: This variety was inherited from the great grand fathers of the farmer. The seed is fairly round in shape with creamy white seed coat and black helium colour. No agronomic and entomological records were available.

Grains of these varieties were sorted out to remove all unwanted materials. Prior to the experiment, the grains were kept in a deep freezer after drying at 2 °C for at least 72 h to kill any unseen insect, eggs or internal infestations. These grains were then allowed to dry for at least an hour prior to weighing to condition them to room temperature before using for the experiment (Swella and Mushobozy, 2007; Ojebode *et al.*, 2016).

c) *C. maculatus* culture

The method for rearing the experimental insects followed the procedure described by Swella and Mushobozy (2007). Adult *C. maculatus* were originally obtained from infested samples of cowpea in a laboratory stock at the University for Development Studies (UDS) and CSIR-Savanna Agricultural Research Institute, Tamale, Ghana. They were reared on cowpea seeds inside a growth chamber of temperature 27 ± 3°C and 50 - 70% relative humidity. A total of hundred (100) pairs of newly emerged (1–24 h old) adults were introduced into each rearing jar containing 500g of cowpea grains.

The jars were covered with pieces of fine nylon mesh cloth at the open ends, and fastened with rubber bands to prevent the contamination of the seeds and escape of the beetles. A maximum of 5 days was allowed for mating and oviposition. The parent beetles were removed afterward, and the seeds containing the eggs were transferred to fresh seeds in rearing jars which were also covered as described above. The rearing was done at the above mentioned temperature and relative humidity after collection for several generations to allow for the multiplication of the weevil for the experiment (Nyamandi and Maphosa, 2013) as shown in Plate 1 below. The subsequent progenies emerging from the stock were used as parental generation for the experiment (Badii *et al.*, 2013).

Plate 1. *Callosobruchus maculatus* culture maintained in the laboratory for use in the experiments.

d) Experimental design and treatments

The experiment was laid out in a Completely Randomized Design (CRD) with seven (7) treatments. The treatments were the seven (7) cowpea varieties described above. Seed grains of each cowpea variety were infested with five (5) pairs of adult *C. maculatus* in a set up with four replications.

e) Experimental procedure

Two hundred (200) grains of each variety, after being weighed to determine their initial weight, were placed in each experimental jar for the infestation. All the cowpea varieties were infested with *C. maculatus* obtained from the stock culture. A total of five (5) pairs of newly emerged (1–24 h old) adults of males and females were selected and introduced into each experimental glass jar containing the 200 cowpea grains. The insects were allowed for 48 hours to mate and lay eggs after which they were removed from the jars with the help of a fine mesh sieve. Individual insects were picked and placed in the experimental glass jar containing the grains with the help of a fine camel hair brush (Figure 2). The experimental glass jars, after infestations, were covered with the perforated lids lined with fine nylon mesh cloth. Each experimental jar was tightly closed and well labeled. They were placed under laboratory conditions maintained at a constant temperature of 27 ± 3°C and 50 - 70% relative humidity.

Observations were made for a maximum of four weeks during which period the appropriate data were collected. The numbers of dead and live beetles were monitored, counted and recorded 7 days after infestation (DAI). Dead beetles were removed and the set up was monitored until the emergence of F1 progenies during which period the necessary data were collected.

Figure 2. Cowpea grains being infested with adult *C. maculatus* in the laboratory.

f) Data collection

Parameters measured included; oviposition, adult developmental period, progeny emergence, grain damage, grain weight loss, grain susceptibility and seed viability.

Oviposition

The number of eggs laid on the seeds of each sample was counted separately following the method described by Lambert *et al.* (1985) using a sample size of 20 seeds randomly selected from each treatment. They were recorded for each treatment one week after the infestation. The grains were then re-incubated till the emergence of the F1 progeny.

Developmental period

After the oviposition, mean developmental period was recorded. This was recorded as the time period taken for the insects to develop from egg to adult stages. This was done by counting the number of days it takes the insect to emerge from each treatment after oviposition through daily monitoring beginning from the time of oviposition.

Adult emergence

The various treatments were examined daily for the proportions of adults that emerged from the number of eggs laid on the seeds, including hatched and unhatched following the method of Asante and Mensah (2007). The emerged adults were removed from each sample by sieving with a fine meshed sieve. F1 progeny assessment started at the time of adult emergence by counting all emerged insects both live and dead ones. After the first emergence, monitoring continued for an additional week to make sure that all eggs laid were hatched (Figure 3). Progeny emergence concluded after four weeks of storage when mortalities of the insects started (Egwurube *et al.*, 2010). This was done to avoid an overlap between emerged adults of the first and the second generations (Musa and Adeboye, 2017).

Grain damage

To determine grain damage rate, samples of 100 grains were taken randomly from each treatment. The number of damaged (grains with characteristic holes) and undamaged grains were counted and the rate calculated using the formula;

Rate of damage = [Nd / (Nd + Nu)] x 100

Where; Nd = Number of damaged grains and

Nu = Number of undamaged grains (Radha and Susheela, 2014; Boakye *et al.*, 2016).

Grain weight loss

Weight loss caused by *C. maculatus* infestation was assessed on the grains of all varieties after the four weeks of storage. The damaged and undamaged grains, after being sorted and counted, were weighed and the weight loss assessment computed using the following formula:

Percentage grains weight loss = [(UNd)-(DNu)/ U (Nd + Nu)] x 100

Where;

U = Weight of undamaged grain,

D = Weight of damaged grain,

Nd = Number of damaged grains and

Nu = Number of undamaged grains (Nalini *et al.*, 2012).

.

Figure 3. Inspecting cowpea grains for infestation and damage by *C. maculatus* in the laboratory.

Susceptibility index

In determining the grain susceptibility, the progeny emergence and the developmental period were considered. Thus, susceptibility index was determined using Dobie's equation adopted by Badii *et al.* (2011) as follows:

Susceptibility index (SI) = ($Log_e\ F_1/D$)* 100 (Dobie 1974; Dobie *et al.*, 1979 and Dobie 1981)

Where:

Log_e = Natural Logarithm

F_1 = Total number of adults emerged and

D = Median developmental period (estimated as the time from the middle of oviposition to the emergence of 50% of the F_1 generations).

The cowpea varieties were grouped differently using Dobie's index of susceptibility scales as follows.

Scale index of < 4.1 as highly resistant;

Scale index of 4.1 – 6.0 as moderately resistant;

Scale index of 6.1 – 8.0 as moderately susceptible;

Scale index of 8.1 – 10 as susceptible;

Scale index of >10 as highly susceptible (Musa and Adeboye, 2017).

Seed viability

To assess seed viability, the procedure used by Mahama (2012) was adopted. The percentage germination was determined using 100 seeds taken randomly from each experimental jar. A total of 20 seeds from the 100 seeds sample were placed in poly ethylene bags containing moistened soil to make five replications for each treatment. Healthy undamaged grains were used as control. The number of emerged seedlings from each poly ethylene bag were then counted and recorded after one week after which the percent germination was computed using the following formula:

Percentage germination or viability (%) = (NG*100)/TG

Where;

NG = Number of grains germinated and

TG = Total number of grains tested in each poly bag.

g) Data analysis

The data collected were transformed using square-root transformation. These were then subjected to analysis of variance using Genstat Statistical Package, 12th edition. General analysis of variance (ANOVA) in Completely Randomized Design (CRD) model was performed for all measured and derived quantitative data. In addition, correlation coefficients of the damage parameters were compared. This was done to find out the relationship between grain susceptibility and the other damage-related parameters using Spearman's correlation co-efficient. Treatment means were separated using Standard Error of Differences (SEDs) at 5% probability level. The results obtained were presented using simple descriptive statistics such as bar charts and tables.

CHAPTER FOUR

1.5 RESULTS

1.6 Oviposition

The results showed that the mean number of eggs laid on the cowpea grains was significantly ($p < 0.05$) affected by the varieties tested. The local check recorded the highest number of eggs. This was however, not significantly different ($p > 0.05$) from Padi-tuya. Apagbaala recorded the next heaviest egg load followed by Marfo-tuya both of which were significantly different ($p < 0.05$) from Padi-tuya and the local check. Songotra on the other hand, recorded the lowest significant ($p < 0.05$) number of eggs followed by Zaayura and Bawutawuta.

There was no significant difference ($p > 0.05$) between Zaayura and Songotra for their egg numbers. Similarly, Zaayura and Bawutawuta were not significantly difference ($p > 0.05$) in terms of egg number. However, the number of eggs on Bawutawuta was significantly higher ($p < 0.05$) than that of Songotra.

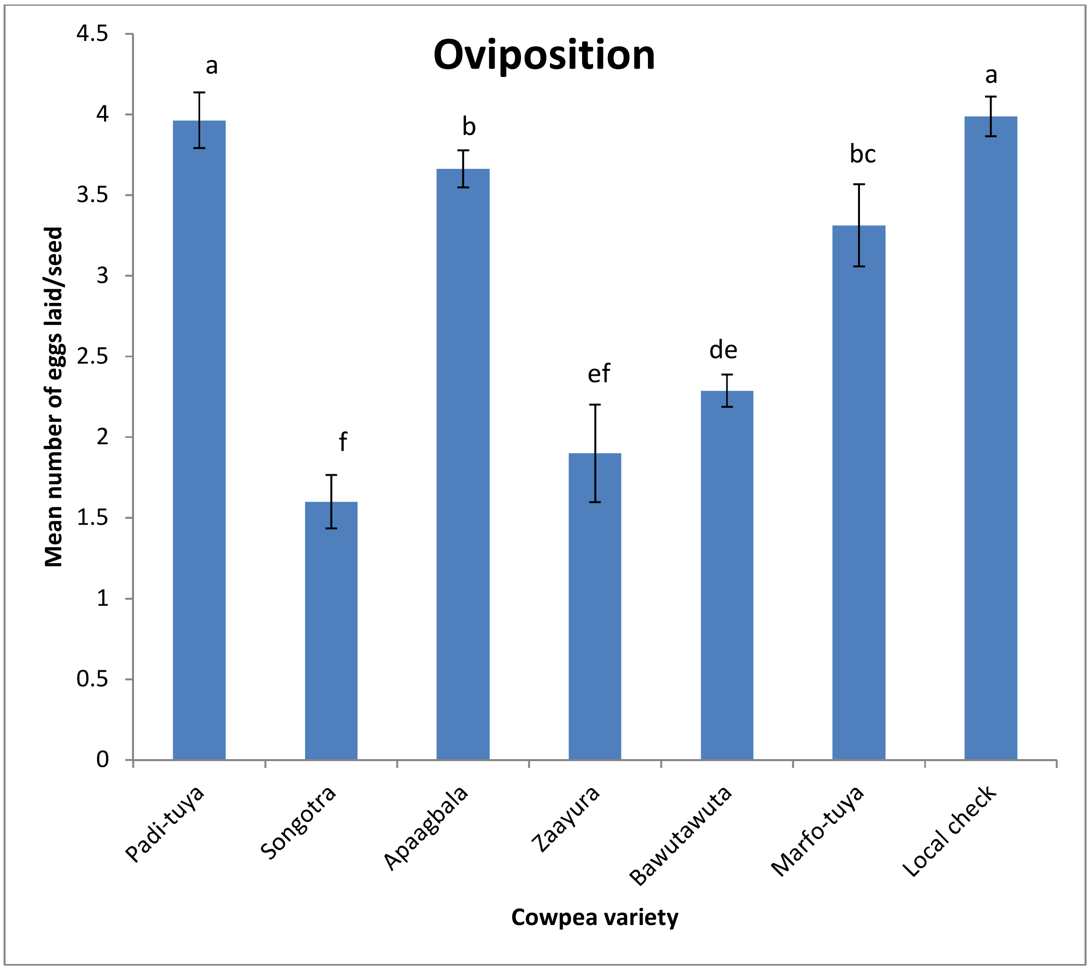

Figure 4. Effect of cowpea variety on the number of eggs laid by the pulse beetle, *Callosobruchus maculatus* (F.). Bars represent Standard Error of the Means (SEMs). Collums with different letters are significantly different at 5% probability level.

1.7 Developmental period

The influence of cowpea variety on the time taken by the adult pulse beetle to develop from egg to adult is presented in Figure 5. Developmental period was significantly affected ($p < 0.05$) by the cowpea varieties tested. The local check recorded significantly shorter developmental period (19 days) than the improved varieties. This was followed by Padi-tuya, Marfo-tuya and Apagbaala. The latter varieties were however, not significantly different ($p > 0.05$) from each other.

Also, the beetle took significantly ($p < 0.05$) higher number of days (23.75 days each) to complete its development in Songotra and Zaayura. This was followed by Bawutawuta with 23.25 days. There was however, no significant difference ($p > 0.05$) in developmental period between the two varieties and Bawutawuta. Overall, mean developmental time was found to range between 19 days and 24 days.

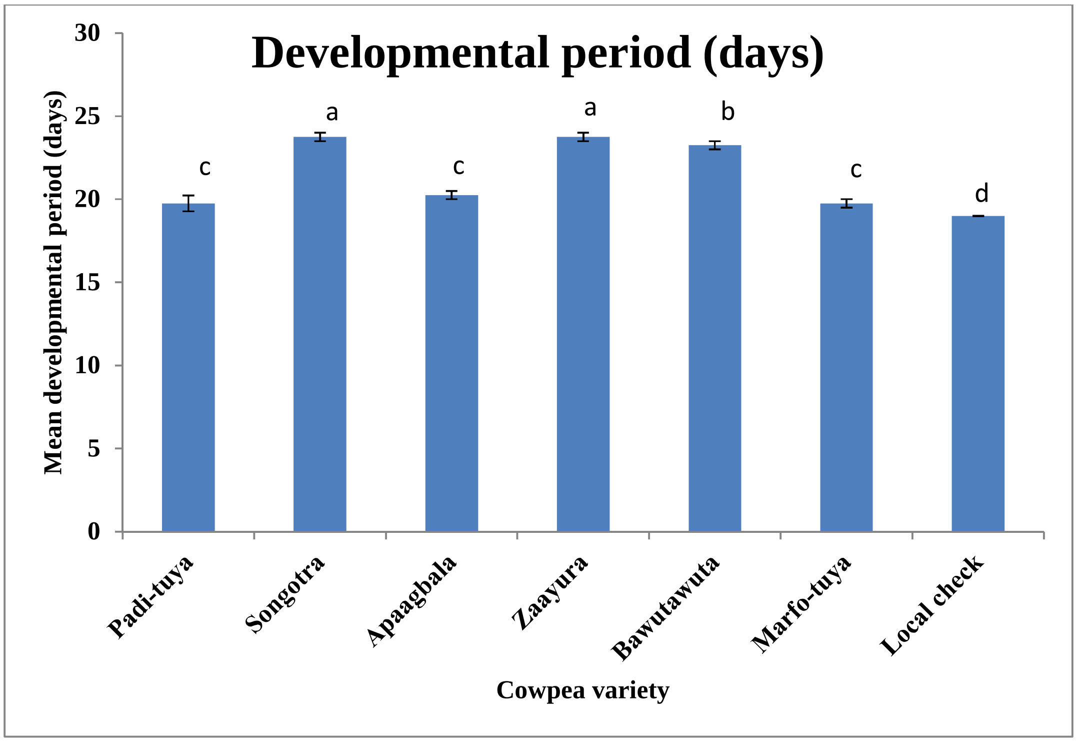

Figure 5. Mean developmental period of the pulse beetle, *Callosobruchus maculatus* (F.) as influenced by cowpea variety. Bars represents Bars represents Standard Error of the Means (SEMs). Collums with different letters are significantly different at 5% probability level.

1.8 Adult emergence

Figure 6 shows the effect of cowpea varieties on the mean adult emergence of *C. maculatus* (F.) from the seed grains during the storage period. The local check recorded significantly ($p < 0.05$) higher number of adult emergence (79) but it was not significantly different from Apagbaala and Padi-tuya. Marfo-tuya also recorded the next high numbers of F1 progeny emergence followed by Apagbaala and Padi-tuya; there was no significant different ($p > 0.05$) between these two varieties.

Adult emergence in Marfo-tuya was significantly differed ($p < 0.05$) from the local check. In contrast, Zaayura had the lowest number of adult insect emergences, but this was not significantly different ($p > 0.05$) from Songotra and Bawutawuta. Emergence in three varieties (Zaayura, Songotra and Bawutawuta) differed significantly from that of the remaining four varieties (Padi-tuya, Apagbaala, Marfo-tuya and the local check).

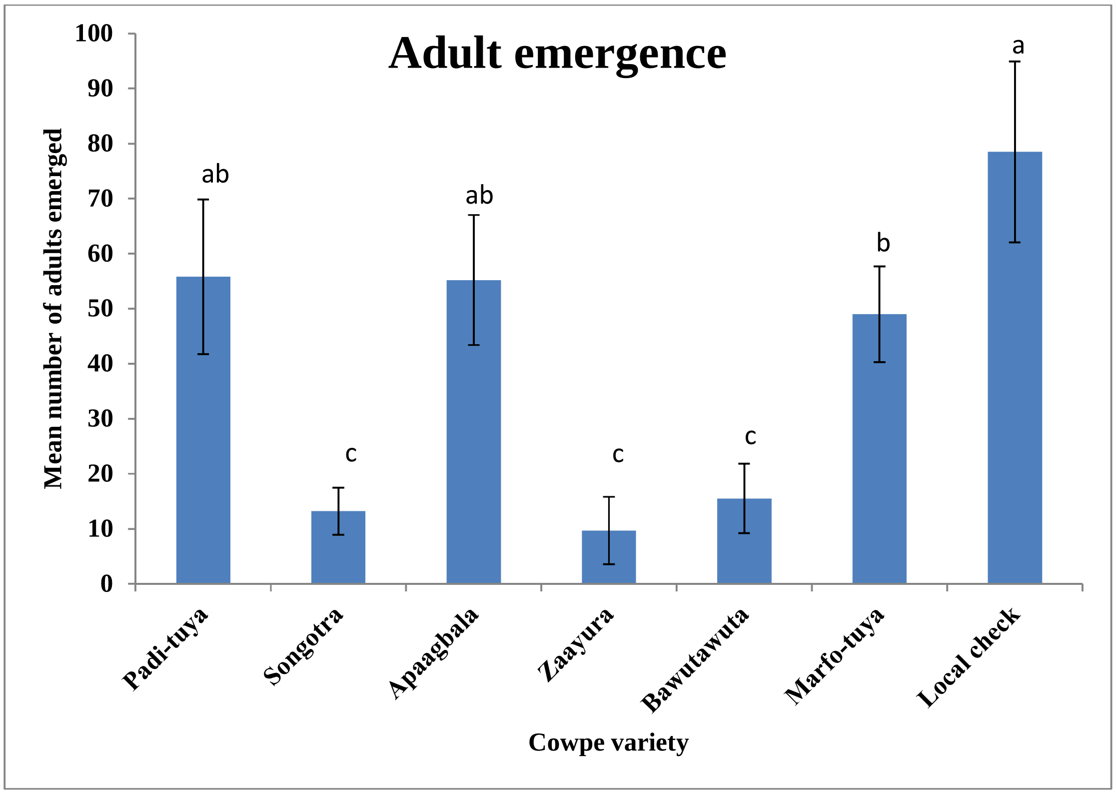

Figure 6. The influence of cowpea variety on adult emergence of the pulse beetle, *Callosobruchus maculatus* (F.). Bars represents Bars represents Standard Error of the Means (SEMs). Collums with different letters are significantly different at 5% probability level.

1.9 Grain damage

Damage by *C. maculatus* as influenced by the different cowpea varieties tested is presented in Table 2. The number of damaged and undamaged grains was significantly affected ($p < 0.05$) by the cowpea variety. The highest damage was recorded on the local check. This was significantly different ($p < 0.05$) from Apagbaala. Padi-tuya also recorded high number of damaged grains and percentage grain damage. This was however not significantly different ($p > 0.05$)

from Apagbaala. In control, number of damaged grains and percentage damaged grains were significantly ($p < 0.05$) lower on Zaayura. This was followed by Marfo-tuya, Songotra and Bawutawuta in an increasing order of percentage damage.

Table 2. Effect of cowpea variety on percentage grain damaged by the pulse beetle, *Callosobruchus maculatus* (F.).

Cowpea variety	**Number of undamaged grains**	**Number of damaged grains**	**Percentage damaged grain**
Padi-tuya	73.0d ± SE	27.0b ± SE	25.50b ± SE
Songotra	93.0b ± SE	7.0d ± SE	11.00c ± SE
Apagbaala	72.0d ± SE	28.0b ± SE	26.50b ± SE
Zaayura	97.0a ± SE	3.0e ± SE	8.00d ± SE
Bawutawuta	94.0a ± SE	6.0de ± SE	11.50c ± SE
Marfo-tuya	89.00c ± SE	11.00c ± SE	10.50cd ± SE
Local check	67.0e ± SE	33.0a ± SE	31.50a ± SE
***SED**	3.238	3.238	2.540
***CV**	5.5	28.6	20.2

Note: Means with different letters are significantly different at 5% probability level. *SED = Standard error of difference, CV=

Songotra and Bawutawuta were also not significantly different ($p > 0.05$) from each other. However, these two varieties were significantly different ($p < 0.05$) from Zaayura. Generally, these four varieties (Zaayura, Songotra, Bawutawuta and Marfo-tuya) recorded low numbers and percentage damaged grains as compared with the first three varieties (Padi-tuya, Apagbaala and the local check) with high numbers and percentage grain damage. On the other hand, the varieties (Zaayura, Songotra, Bawutawuta and Marfo-tuya) recorded high numbers of undamaged grains compared to the remaining three varieties (Padi-tuya, Apagbaala and the local check).

1.10 Grain weight loss

The losses in weight of cowpea grains due to infestation by the pulse beetle are presented in Table 3. Weight loss was found to be significantly different ($p < 0.05$) among the cowpea varieties. When grain weight loss was converted into percentages, significant differences ($p < 0.05$) were still observed among the varieties. Mean and percentage grain weight loss were highest in Apagbaala, Padi-tuya and the local check. On the other hand, Bawutawuta, Zaayura, Songotra and Marfo-tuya recorded the lowest mean and percentage grain weight loss.

Mean grain weight loss and percentage grain weight loss in Bawutawuta was significantly ($p < 0.05$) lower than that of Songotra, Zaayura and Marfo-tuya. There were significant differences among Songotra, Zaayura and Marfo-tuya in terms of their mean grain weight loss. However, there were no significant difference between Songotra and Zaayura for their percentage grain weight loss but these differed from Marfo-tuya. Also, grain weight loss in Padi-tuya and Apagbaala were not significantly different ($p > 0.05$) from the local variety.

Table 3. Effect of cowpea variety on grain weight loss due to the pulse beetle, *Callosobruchus maculatus* (F.) infestation.

Treatment/ Cowpea variety	**Weight of undamaged grains**	**Weight of damaged grains**	**Mean grain weight loss**	**Percentage grain weight loss**
Padi-tuya	16.39c ± SE	3.61b ± SE	2.000a ± SE	9.09c ± SE
Songotra	15.13d ± SE	0.62de ± SE	1.250cd ± SE	7.35e ± SE
Apagbaala	13.23f ± SE	2.77c ± SE	2.000a ± SE	11.11a ± SE
Zaayura	19.32a ± SE	0.18ef ± SE	1.500b ± SE	7.14e ± SE
Bawutawuta	17.70b ± SE	1.17d ± SE	1.125d ± SE	5.63f ± SE
Marfo-tuya	16.11c ± SE	0.52e ± SE	1.375c ± SE	7.64d ± SE
Local check	14.38e ± SE	4.49a ± SE	2.125a ± SE	10.12b ± SE
SED	0.497	0.559	0.1890	0.956
CV	4.4	41.5	16.4	16.3

Note: Means with different letters are significantly different at 5% probability level. *SED = Standard error of difference, CV=

1.11 Susceptibility index

The indices of susceptibility of the different cowpea varieties to the pulse beetle infestation are presented in Figure 7. Grain Susceptibility to the beetle was significantly ($p < 0.05$) affected by the varieties tested. The local variety (check) had a significantly ($p < 0.05$) higher susceptibility index but it was not significantly different ($p > 0.05$) from Padi-tuya. Zaayura recorded significantly ($p < 0.05$) lower susceptibility index followed by Songotra and Bawutawuta. Grain susceptibility was not different ($p > 0.05$) among Marfo-tuya, Apagbaala and Padi-tuya though Padi-tuya recorded a higher susceptibility than the others. When the seven varieties were ranked in order of their relative susceptibilities using parameters such as oviposition, developmental period, adult emergence, grain damage and grain weight loss, Zaayura, Songotra and Bawutawuta were still found to be the least preferred or resistant varieties while Marfo-tuya, Apagbaala, Padi-tuya and the local check were the most preferred or susceptible varieties to *C. maculatus* attack (Table 4).

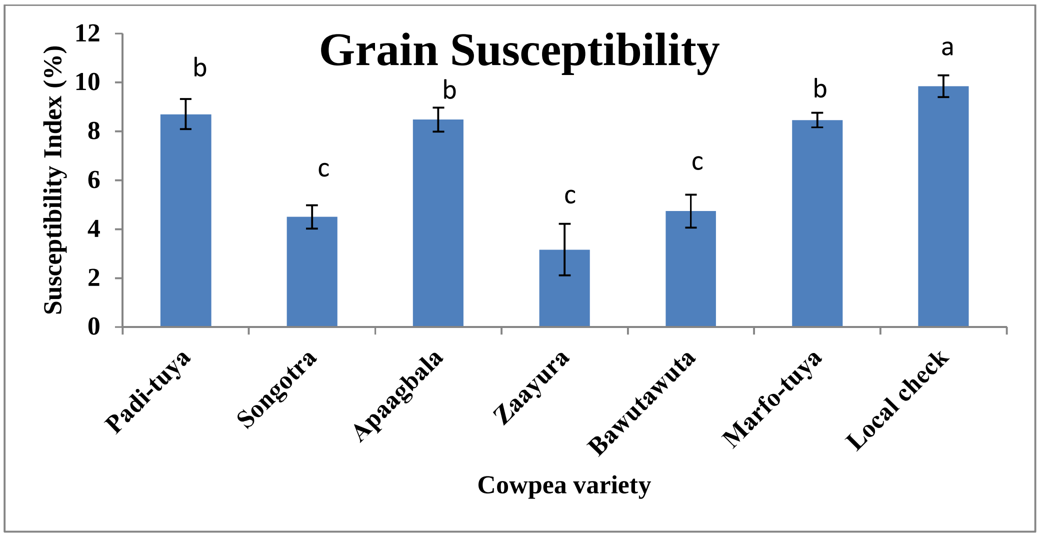

Figure 7. Cowpea grain susceptibility to the pulse beetle, *Callosobruchus maculatus* (F.) as influenced by varietal differences. Bars represents Bars represents Standard Error of the Means (SEMs). Collums with different letters are significantly different at 5% probability level.

Table 4. Ranking of the different cowpea varieties in order of relative susceptibility to *Callosobruchus maculatus* (F.).

Cowpea varieties	Mean No. of eggs laid	Mean developmental period	Mean number of adults emerge	% grain damage	% grain weight loss	Susceptibility index	Total ranks	Mean ranks
Padi-tuya	6	2	6	5	5	6	30	5
Songotra	1	5	2	3	3	2	16	2.7
Apagbaala	5	3	5	6	7	5	31	5.2
Zaayura	2	5	1	1	2	1	12	2
Bawutawuta	3	4	3	4	1	3	18	3
Marfo-tuya	4	2	4	2	4	4	20	3.3
Local check	7	1	7	7	6	7	35	5.8

*Infestation and damage: 1 = least susceptible/infested, 7 = most susceptible/infested

1.12 Seed viability

Germination was significantly different among the varieties. The local check recorded the lowest germination percentage while Songotra was the highest. The local check was however not significantly different ($p > 0.05$) from Apagbaala and Padi-tuya. Germination percentage of seeds of Songotra was not significantly (p > 0.05) different from those of Zaayura. Bawutawuta and Marfo-tuya were next in decreasing order of grain viability. In general, Padi-tuya, Apagbaala and the local check recorded very low germination percentages while Marfo-tuya, Bawutawuta, Zaayura and Songotra had the highest percentage germinations.

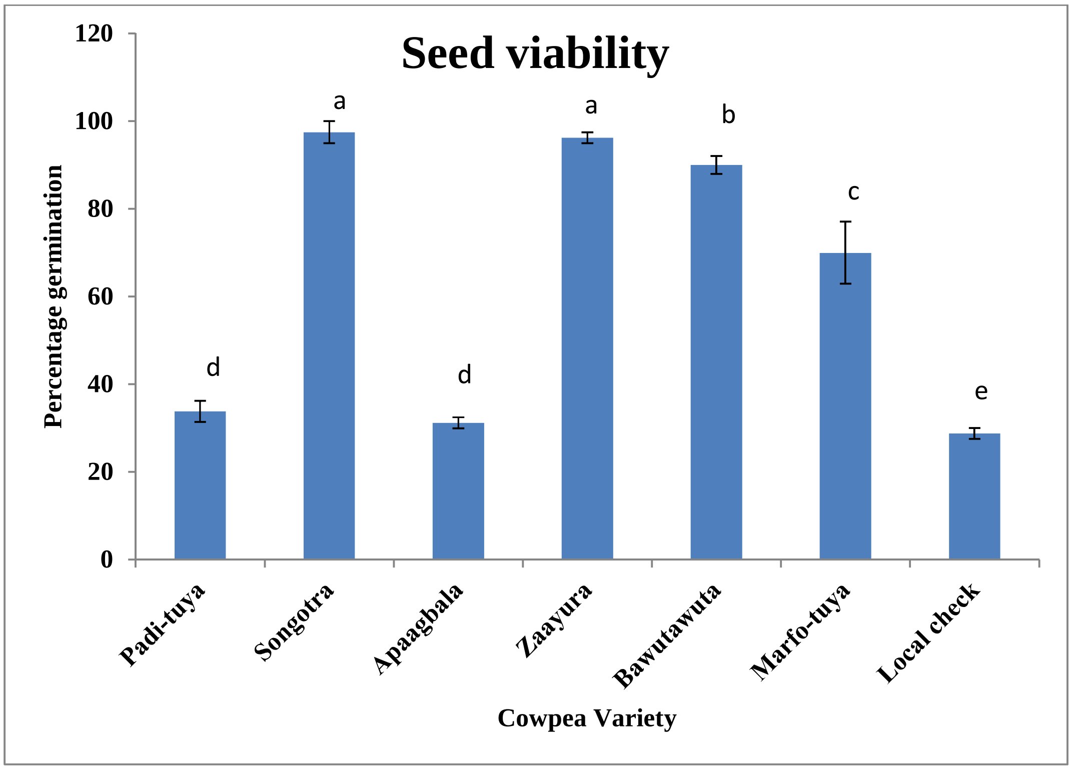

Figure 8. The effect of variety on viability of cowpea seeds after infestation with the pulse beetle, *Callosobruchus maculatus* (F.)**.** Bars represents Standard Error of the Means (SEMs). Collums with different letters are significantly different at 5% probability level.

1.13 **Relationship between the damage parameters**

The results showed that susceptibility correlated positively with oviposition, grain damage, adult emergence and percentage grain weight loss but negatively with adult developmental period and seed viability. There was highly significant difference ($p < 0.001$) between susceptibility and these parameters. Seed viability and susceptibility there showed a significant negative correlation.

Grain weight loss also correlated positively and significantly ($p < 0.05$) with oviposition, grain damage and adult emergence but negatively with adult developmental period and seed viability.

Also, grain damage correlated positively with adult insect emergence but negatively with the adult developmental period and seed viability. There was positive correlation between oviposition and adult insect emergence and grain damage. In general, number of eggs laid, adult insect emergence, grain damage and grain weight loss all positively influenced the susceptibility levels of the cowpea varieties. The developmental period and grain viability negatively influenced the susceptibility of the grains to the beetle.

Table 5. Correlation coefficients of damage related parameters used to determine the susceptibility of cowpea varieties to *Callosobruchus maculatus* (F.).

	% Susceptibility	Oviposition	Developmental period	Adult insect emergence	Grain Damage	% Grains weight loss	Seed viability
%Susceptibility	**1.000**						
Oviposition	**0.843****	**1.000**					
Developmental period	**-0.865****	**-0.825****	**1.000**				
Adult insect emergence	**0.984****	**0.834****	**-0.805****	**1.000**			
Grain Damage	**0.729****	**0.766****	**-0.658****	**0.743****	**1.000**		
% Grains weight loss	**0.599****	**0.470***	**-0.556****	**0.629****	**0.639****	**1.000**	
Seed viability	**-0.768****	**-0.809****	**0.847****	**-0.757****	**-0.801****	**-0.744****	**1.000**

*Significant at $p \leq 0.05$; **highly significant at $p \leq 0.01$.

CHAPTER FIVE

1.14 DISCUSSION

1.15 Oviposition

This study have showed that the cowpea varieties; Songotra, Zaayura and Bawutawuta, have some degree of resistance to *C. maculatus* infestation. Marfo-tuya, Apagbaala and Padi-tuya more susceptible and they were preferred for oviposition. Nwanze *et al.* (1975) reported that *C. maculatus* would choose smooth-coated and well-filled seeds to those that are rough and wrinkled for oviposition. Mbata (1992) found that the surface area of cowpea seed varies among varieties, and number of eggs laid per seed was positively correlated with the surface area. These qualities of the seed may parcially explain why eggs were not equally distributed among seeds of the seven different cowpea varieties as they possessed different surface areas and rough seed coats (Jackai and Asante, 2003; Abdel-Fattah and Ahmed, 2007). According to Musa and Adeboye (2017), the size of cowpea seeds may provide suitable site and nourishments for egg-laying and subsequent development of *C. maculatus*. Moreover, the suitability of cowpea seed type for oviposition by *C. maculatus* is influenced by surface area and curvature of the seeds (Badii *et al.*, 2013B).

Cope and Fox, (2003) observed that female *C. maculatus* evaluates the relative quantity of resources available inside of a seed more accurately than if they compared the ratio of surface areas between seeds of varying sizes. Cope and Fox (2003) further observed that bruchids females do not only deposit more eggs on the larger grains but also distributes their eggs according to the relative mass of the grains available. This possibly explains the high preference for Padi-tuya, Apagbaala, Marfo-tuya and the local variety to the beetle. Apagbaala sustaining higher egg load than Zaayura implied that preferences for oviposition was influenced by other factors but not just the size and mass of grains. This is confirmed by Allotey *et al.* (2011) who reported that size of grains apparently had no effect on the oviposition of the adult *C. maculatus.* They however, attributed the different ovipositional choice to surface odors and the chemical composition of the seed coat; this is another important reason for the ovipositional differences.

Grains of different cowpea varieties are composed of different chemicals and this makes them to appear and taste different from each other (Ignacimuthu, 1999). Studies of Ignacimuthu (1999) and Keneni *et al.* (2011) showed that, there are secondary metabolites (polymers like lignins and tannins, alkaloids, quinines, etc.) that play important role in seed defense against insects. These metabolites may act as repellents, feeding inhibitors and anti-nutritional factors. Augustine *et al.* (2016) documented various grain properties including the testa colour, mass, size and moisture content as properties of the seed that influences the susceptibility of cowpea and other cereals grains to *C. maculatus* in storage. This suggests that Zaayura and Bawutawuta, which had bigger and heavier grains than Songotra, possibly had more of these metabolites consequently resulting in them being less preferred by the insect.

Seed coat textural differences were another reason that could explain the differences in oviposition by the beetle. According to Blumer and Beck (2008), at the stage of oviposition, a female bruchid carefully chooses the oviposition site for her offspring. It does so because the choice influences the growth, survival and reproduction of its subsequent generations (Fox, 1993). Perhaps, the characteristics of Apagbaala and Padi-tuya made them the most preferred for oviposition. These varieties are improved with larger grain sizes and very soft seed coats compared to Zaayura and Bawutawuta. This finding is corroborated by Baidoo *et al.* (2015) who reported that grains with thinner seed coats were better accepted for oviposition than their thicker-coated counterparts.

1.16 Adult emergence and developmental period

Developmental period of *C. maculatus* was recorded as the time taken to develop from egg laying to adult emergence. The extent of this period actually depended on several factors. The nature of substrate, temperature and relative humidity are some of the factors that might affect the developmental period of *C. maculatus* (Wright, 1986 and Osman *et al.*, 2015). Suitable substrate facilitated the developmental time of the insect. When *C. maculatus* was reared within the confinement of the required temperature and relative humidity, the number of days to complete development by the insect was determined by a preferred host. In a situation where temperature and relative humidity were taken in to consideration, host preference was determined based on the egg-adult developmental time of the beetle (Osman *et al.*, 2015). From the data collected in this study, Songotra, Zaayura and Bawutawuta negatively influenced the developmental period of the beetle by delaying the number of days taken to emerge after oviposition. Apart from the low developmental period, the highest mean number of progeny emergence was also observed on the local variety, Padi-tuya, Marfo-tuya and Apagbaala. This observation suggests that they might have softer and more preferable endosperm and seed coat as reported by (Silva *et al.*, 2004). It also suggests that these varieties have less or no chemical constituents or insecticidal properties that could hinder the insects' developmental period. This resulted in the insects feeding voraciously to grow from one larval instars' to the other.

The study also found that the varieties-Songotra, Zaayura and Bawutawuta recorded longer (> 23 days) developmental period of above 23 days while the susceptible varieties- Padi-tuya, Apagbaala, Marfo-tuya and the local check had shorter (< 21 days) developmental period. This finding agrees with that of Musa and Adeboye (2017) who reported the median developmental period as the range of 23-31days. This however contrasted findings of Beck and Blumer (2007), who reported that the mean life cycle of *C. maculatus* on susceptible varieties ranged between 21 and 25 days.

According to Wright (1986), the period of development from egg to adult varies with environmental conditions such as temperature and relative humidity but Dick and Credland (1984) stated that at 27 ^{0}C and 70% rh, the developmental period of the insect is about 30 days. Devi and Devi (2014) also reported same developmental time at 28.5 ±2.0 ^{0}C and 78.5± 3.0% rh. These findings could not be corroborated by the results of this study.

The higher number of adult emergence recorded on the local variety, Padi-tuya, Apagbaala and Marfo-tuya could be due to the high oviposition and less developmental period recorded on them. This confirms the report of Musa and Adeboye (2017) that a higher number of adult *C. maculatus* emerging on a cowpea variety with the shortest median developmental period suggest that the median developmental period played an important role in cowpea grain infestation. Badii *et al.* (2011) reported that the prolonged egg development and few progenies emerging from a legume variety means the variety is resistant confirming this finding.

The pattern of adult emergence of *C. maculatus* in resistant cowpea varieties are characterized by delayed, staggered and slow adult emergence while in the susceptible varieties, adult emergence are relatively early and extremely rapid leading to the extensively damaging results obtainable from those varieties. This further explains the prolonged egg development and few progenies emerging from Zaayura, Songotra and Bawutawuta as compare to the remaining varieties. The finding is also confirmed by that of Augustine *et al.* (2016) who reported that when a variety showed higher mean number of eggs it is susceptible to *C. maculatus*. The findings of this study suggest that the number of emerging adult determines the extent of damage, and consequently, grains permitting more rapid and higher levels of adult emergence will be more extensively damaged by *C. maculatus*. This confirms findings of Torres *et al.* (2016) who stated that higher emergence of adult insect results in higher quantitative damage, loss of bean nutritional quality, and negative effects on bean appearance, which makes them unsuitable for commercialization and consumption.

1.17 Grain damage, weight loss and susceptibility index

As was documented by Badii *et al.* (2013B) and Torres *et al.* (2016), the extent of damage and subsequent weight loss of cowpea grains highly depends on the number of adult emergence of *C. maculatus* on the grain. Thus, the higher the number of F1 progeny emergence on a particular variety, the higher the damage and weight loss of that variety and the vice versa. Damage caused by *C. maculatus* from this study followed the pattern of emergence above. Damage was significantly highest on the local variety followed by Apagbaala and Padi-tuya and this confirms the findings from similar studies (Adam and Baidoo, 2008; Amusa *et al.*, 2013; Mogbo *et al.*, 2014) that *C. maculatus* has the ability to cause severe damage to cowpea seeds. The low damage on Zaayura, Marfo-tuya, and Songotra might be due to their inherent chemical constituents which makes them unacceptable to the insect. Kananji (2007) reported that the chemical factors responsible for resistance to storage pest included; arcelin in the cotyledons, tannins in the seed coat, and phytohemagglutinin (PHA) within the seed including α-amylase inhibitors. He explained that antibiosis or non-preferential resistance mechanisms to bruchid infestation by the legume grains are explained using the presence of these chemical factors in the legume grains. This was also supported by Baidoo *et al*. (2015) who said that light-coloured seeds even though higher in protein and carbohydrates have poor resistance to cowpea beetle infestation during storage.

Desroches *et al.* (1995) found out that the seed coat in a faba bean (*Vicia faba*) acts as a physical barrier against damage by *C. chinensis* and *C. maculatus*. Edde and Amatobi (2003) and Oliveira *et al.* (2018) also reported similar type of resistance against *C. maculatus* on cowpea grains. In contrast, Lale and Kolo (1998) observed that resistance to *C. maculatus* in three cultivars of cowpea was due to a combination of reduced oviposition and egg-hatching which might be caused by chemical rather than physical characteristics of the seed coat. Similarly, Fawki *et al.* (2012) reported that the seed coat texture did not play a role in protecting cowpeas from the beetles attack. Thus, host plants may use nutritional, physiological and ecological hurdles on the insects (Panda and Khush, 1995) leading to its resistance or susceptibility as observed in this study.

According to Torres *et al.* (2015), loss in mass of grains positively correlates with the number of emerged insects. This loss is an important parameter to measure both from an economical point of view and as an indicator of a cowpea variety's resistance to *C. maculatus*. This is explained by the fact that the feeding activities of the insect leads to the perforations (damage). It is therefore this damage which brings about the reduction in the weight loss experienced by the grains.

Bawutawuta, Zaayura and Songotra loss the least weight among all the grains tested. Grains of Apagbaala, Padi-tuya and the local variety loss significant amount of their weight to the insect's damage and this made them unacceptable by the consumers since the nutritional and physical qualities are also affected. This corroborates the finding of Torres *et al.* (2015) that higher emergence of adult insects' results in higher quantitative damage, loss of bean nutritional quality, and negative impacts on bean appearance. This makes the grains unacceptable for marketing and consumption by the public. Also, Mofunanya and Namgbe (2016) reported that infestation of cowpea by *C. maculatus* caused reduction in protein, moisture and carbohydrate with increase in ash, fiber and fat content of the seed.

Based on the observation made in this study, the local variety, Padi-tuya, Marfo-tuya and Apagbaala are classified as being highly susceptible while Songotra and Bawutawuta are moderately resistant. Zaayura was however, highly resistant since it recorded the lowest susceptibility index of < 4 (3.16). This classification is consistent with the findings of Musa and Adeboye (2017) who classified varieties with the susceptibility index between 6.1 and 10 as susceptible and those between 4.1 and 6 as moderately resistant based on the Dobies' index of susceptibility (Dobie 1974; Dobie *et al.*, 1979 and Dobie 1981).

1.18 Seed viability

Germination test best explains how viable the seed is. However, this test is sometimes influenced by certain factors such as environmental conditions in addition to the damage caused by insect pest and disease. Damage as a result of the insect pest infestation on cowpea leads to perforations on the grains. These perforations translate to loss in viability as a result of the loss of the grains' endosperm and sometimes the radicals.

Grains of the different varieties tested in this study were subjected to the test of germination at the end of the experiment. This was done to determine the effect of

C. maculatus infestation and damage on the viability of these grains. It was found that infestation and damage by *C. maculatus* negatively influenced the viability of the seed. This was based on comparison of the germination between uninfested/undamaged and the infested/damaged grains where the undamaged varieties had high germination percentage and the damaged varieties with very poor and low germination percentage. These differences were observed as a result of the damage differences in those varieties. This observation supports that of Mofunanya and Namgbe (2016) who stated that the damage to cowpea seed by *C. maculatus* affects seed.

It is therefore realized from the results that grains from Songotra, Zaayura, Bawutawuta and Marfo-tuya can be used as seeds for planting after storage without protection but with varying seeds per hill. This cannot be true for the local variety, Padi-tuya and Apagbaala since they had low percentage germinations of less than 60%. This is in line with findings of Mahama (2012) who stated that above 85% of emerged cowpea seedlings, number of seeds per hill should be two; 70 – 84%, 3 seeds per hill; 60 – 70%, 4 seeds per hill and below 60%, the seeds have to be discarded for new seeds. It can therefore be deduced from the mean number of eggs deposited coupled with the emergence that when cowpea seed is infested with *C. maculatus* eggs, resulting in the damage of the seed, germination will be impaired depending on the damage level.

1.19 Correlation between the damage related parameters of *C. maculatus*

Jackai and Asante (2003) and Ewedairo *et al.* (2015) reported in their studies variables such as adult emergence, developmental period and seed weight loss to be the most reliable indicators for resistance of seeds to damage caused by grain borers such as *C. maculatus* and *Prostephanus truncatus* infestations in storage. In this work, varieties that had high oviposition, adult insect emergence, grain damage and weight loss were high in susceptibility index. This implied that those varieties are susceptible while those with lower susceptibility index are resistant varieties. Adam and Baidoo (2008) also reported a positive correlation between susceptibility and number of adult insect emergence. Hence, the results indicated that the lower the developmental period and seed viability, the higher the susceptibility and the vice versa. Though there was highly significant difference between the two parameters and susceptibility, there existed negative correlation between them. That is, those varieties that recorded low developmental periods of the adult insect and percentage germination are susceptible whilst those with the higher adult developmental time and seed vability are resistant varieties.

Grain weight loss also correlated positively with oviposition, grain damage and adult insects' emergence but negatively with adult developmental period and seed viability. This observation is consistent with that of Musa and Adeboye (2017) who reported that the number of emerged adults was highly significant and positively correlated with the percentage grain weight loss.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

From the findings of this study, the following conclusions could be made;

- Among the cowpea varieties tested, Zaayura, Songotra and Bawutawuta demonstrated lower susceptibility to infestation and damage by *C. maculatus*.
- Zaayura was highly resistan while Songotra and Bawutawuta were moderately resistant.
- It was also found that the local variety (check), Padi-tuya, Apagbaala and Marfo-tuya were highly susceptible. These varieties consistently demonstrated higher susceptibility to infestation and damage by *C. maculatus.*
- The results showed that resistance in these cowpea grains are due to physical characteristics such as surface area, smoothness and curvature of the grains.
- In addition, it was also observed that the resistance could be due to chemical inhibitors such as trypsin, arcelin, aminophenylalanine, α-amylase inhibitors and lectins which may be present in grain legumes seeds conferring resistance in them.

6.2 Recommendations

From the conclusion made from the finding of this study, the following recommendations could be made;

- ✓ Zaayura, Songotra and Bawutawuta which are resistant varieties can therefore be recommended to farmers for the management of *C. maculatus* in storage.
- ✓ These resistant varieties can be included in breeding programmes that aim at producing varieties that are resistant to *C. maculatus* in storage.
- ✓ Further work should be should be conducted to assess the role of these physical characteristics as well as the chemical composition and phenol content of these cowpea varieties in relation to the seed damage indices.
- ✓ There is also the need to conduct studies on the varieties to document the relationship between storage period and susceptibility of these varieties to *C. maculatus* infestation.

REFERENCES

❖ Abdel Fattah, H. M. and Ahmed, S. M. (2007). Physical and biochemical Characteristics of some resistant fiber bean genotypes in relation to

Callosobruchus maculatus infestation. *Journal of Egyptian Academic, Social and Environmental Development 8(3): 37-44*.

❖ Abdullahi, A. Usman, I. S. Girei, A. A. and Isma'il, G. (2016). Examination of Indigenous Storage Methods of Cowpea (*Vigna unguiculata*) in Mubi South Local Government Area, Adamawa State, Nigeria. *Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development 16(3): 16.*

❖ Abokersh, M. O. and Barakat, E. M. (2015). Physicochemical Properties of selected varieties of cowpea seeds and their relation to the infestation potential by the cowpea bruchid, *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *Journal of marine sciences and environmental technologies 1(2).*

❖ Adam, J. I. and Baidoo, P. K. (2008). Susceptibility of five cowpea varieties to attack by *Callosobruchus maculatus* (F.) [Coleopteran: Bruchidae]. *Journal of Ghana Science Association 10(2).*

❖ Ahmad, N. Sarwar, M. Khan, G. Z. Tofique, M. and Salam, A. (2011). Efficacy of Some Plant Products and Synthetic Chemicals to Manage the Outbreak of Mealy Bug (*Maconellicoccus hirsutus*) in Cotton. *Journal of Agriculture and Biological Sciences 3 (1): 16-21*.

❖ Ahmady, A. Mousa, M. A. A. and Zaitoun, A. A. (2017). Efficacy of Some Botanical Oils against Stored-product Pest Cowpea Beetle, *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *International Journal of Zoology Studies 2(1):05-09.*

❖ Ahmed, H. (1983). Losses incurred in stored food grains by insect pests - a review. *Pakistani Journal of Agricultural Research 4(3): 1983.*

- Ahmed, B. I. and Yusuf, A. U. (2007). Host–plant resistance: A viable non–chemical and environmentally friendly strategy of controlling stored products pests-a review. *Emironmental Journal of Food and Agriculture 19 (1): 01-12 Available at* http://www.cfa.uaeu.ac.ae/research/ejfa.htm (accessed on : *15/01/2017)*.
- Ahmed, I. A. Kutama, A. S. Hassan, K. Y. and Dangoora, I. I. (2014). Comparative efficacy of neem (*Azadirachta indica* (A.) Juss.) powder against cowpea beetle *Callosobruchus maculatus* (F.) on stored cowpea seeds. *Standard Research Journal of Agricultural Sciences 2 (4): 049-053.*
- Ali, K. and Habtewold, T. (1993). Research on Insect Pests of Cool-Season Food Legumes. In Cool-Season Food Legumes of Ethiopia. Proceedings of the First National Cool-Season Food Legumes Review Conference, Addis Ababa, Ethiopia. pp. 367-396.
- Allahvaisi, S. Pourmirza, A. A. Safaralizade, M. A. (2010). Control of *Callosobruchus maculatus* (Coleoptera: Bruchidae) in industry of packaging food stuffs. *Roman Journal of Biology – Zoology 55(2): 167–176.*
- Allen, D. J. (1983). *The Pathology of Tropical Food Legumes*: Disease Resistance in Crop Improvement. *John Wiley & Sons, Chichester.*
- Allotey, J. Seado, M. Makate, N. and Mpho, M. (2011). Developments of *Callosobruchus maculatus* (F.) on some pulses in Botswana. *Journal of Applied Zoology and Resarch 22(2): 131-137.*

- Amevoin, K. Sanon, A. Apossaba, M. and Glitho, I. A. (2007). Biological control of bruchids infesting cowpea by the introduction of *Dinarmus basalis* (Rondani) (Hymenoptera: Pteromalidae) adults into farmers' stores in West Africa. *Journal of Stored Products Research 43(3): 240-247.*
- Amusa, O. D. Ogunkanmi, A. L. Bolarinwa, and Ojobo, O. (2013). Evaluation of four cowpea lines for bruchid (*Callosobruchus maculatus*) tolerance. *Journal of Natural Science Research 3 (13): 46-52.*
- Asante, S. K. and Mensah, G. K. W. (2007). Evaluation of susceptibility of some elite cowpea cultivars to attack by *Callosobruchus maculatus* Fab. (Coleoptera: Bruchidae). *Ghana Journal of Agricultural Sciences 40:73-80.*
- Aslam M., Shaheen F. A., Abbas M. A., Saba A., (2006). Management of *Callosobruchus chinensis* Linnaeus through use of resistance in stored chickpea varieties. *World Journal of Agricultural Sciences 2: 82-84.*
- Augustine, A. M. Idoko, J. E. Adepoju, A. O. (2016). Ovipositional Response of Seed Beetle *Callosobruchus Maculatus* (F.) Coleoptra: Chrysomelidae on Some Selected Varieties of Cowpea, *Vigna Unguiculata* (L.) Walp. *International Journal of Research in Agriculture and Forestry 3: I5.*
- Badii, K. B. Asante, S. K. and Bayorbor, T. B. (2011). Susceptibility of some Kersting's groundnut landrace cultivars to infestation by *Callosobruchus maculatus* (FAB.) [Coleoptera: Bruchidae]. *Journal of Science and Technology 31(3): 11-21*

❖ Badii, K. B. Charles, A. Obeng, O. D and Christian, U. (2013A). Efficacy of diatomaceous earth formulations against *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) in Kersting's groundnut (*Macroteloma geocarpum* Harms): Influence of dosage rate and relative humidity. *Journal of Pest Science. DOI 10.1007/s10340-013-0548-0.*

❖ Badii, K. B. Asante, S. K. and Sowley, E. N. K. (2013B). Varietal Susceptibility of Cowpea (*Vigna Unguiculata* L.) to the storage beetle, *Callosobruchus Maculatus* (F.) (Coleoptera: Bruchidae). *International Journal of Scientific and Technology Research 2(4).*

❖ Baidoo, P. K. Mochiah, M. B. and Owusu-Akyaw, M. (2010). The effect of time of harvest on the damage caused by the cowpea weevil *Callosobruchus maculatus* (Fab.) (Coleoptera: Bruchidae). *Journal of Stored Products and Postharvest Research 1(3): 24 -28 http://www.academicjournals.org/jsppr. (Accessed on:13/05/2017)*

❖ Baidoo, P. K. Kwansa, N. A. and Annin, C. P. (2015). The role of seed coat and its pigmentation on the acceptance of bambara groundnut (*Vigna subterranea* L. Verdc.) cultivars by the cowpea beetle, *Callosobruchus maculatus* (F.). *Advances in Entomology 3: 125-131. http://dx.doi.org/10.4236/ae.2015.34015. (Accessed on 15/05/2017)*

❖ Bayih, T. (2014). Synergistic bio-efficacy of insecticidal plants against bean bruchids (*Zabrotes subfasciatus*: Coleoptera) a major storage pests of common bean (*Phaseolus vulgaris* l.) in central rift valley of Ethiopia.

MSc. Thesis Submitted to the Department of Biology, School of Graduate Studies Haramaya University.

- Beck, C. W. and Blumer, L. S. (2007). Bean beetles, *Callosobruchus maculatus* (F.), a model system for inquiry-based undergraduate laboratories. *ABLE 2006 Proceedings 28: 274-283.*
- Beck, C. W. and Blumer, L. S. (2014). Life cycle of bean beetles, *Callosobruchus maculatus* (F.) (Coleoptera: Chrysomelidae). http://www.carolina.com/teacher-resources/Interactive/life-cycle-of-bean-beetles. (Accessed on: 22/11/2017)
- Beck, C.W. and Blumer, L. S. (2014). A Handbook on Bean Beetles, *Callosobruchus maculatus* (F.). *National Science Foundation, DUE-0535903, DUE-0815135, and DUE-0814373.*
- Blumer, L. S. and Beck, C. W. (2008). Oviposition substrate choice by bean beetles, *Callosobruchus maculatus*. In: Clase, K.L., Ed., Tested Studies for Laboratory Teaching, Vol. 29. Proceedings of the 29th Workshop/Conference of the Association for Biology Laboratory Education (ABLE), 433.
- Boeke, S. J. Baumgarta, I. R. Jvan Loona, J. A. van Huisa, A. Dickea, M. and Kossoub, D. K. (2004). Toxicity and repellence of African plants traditionally used for the protection of stored cowpea against *Callosobruchus maculatus. Journal of Stored Product Research 2004 40: 423-438.*

- Bressani, R. (1985). Nutritive value of cowpea. In: Singh, S. R. & Rachie, K. 0. Cowpea: Research, Production and Utilisation. John Wiley and Sons, Chichester, Pp 535-360.
- Brisibe, E. A. Adugbo, S. E. Ekanem, U. Brisibe, F. Figueira, G. M. (2011). Controlling bruchid pests of stored cowpea seeds with dried leaves of Artemisia annua and two other common botanicals. *African Journal of Biotechnology 10(47): 9586-9592.*
- Brown, W. B. (1954). Useful plants in the Philippines. *Vol. 2. Department of Natural Resources, Republic of Philippines.*
- Burkil1, I. H. (1935). A dictionary of the economic products of the Malay Peninsula. *Vol. II. Ministry of Agriculture and Cooperations, Kuala Lumpur, Malasia.*
- CABI, (2004). Crop protection Compedium. *Wallingford, UK: CAB International. CD-ROM.*
- Carsky, R. J. Vanlauwe, B. Lyasse, O. (2002). *Cowpea rotation as a resource management technology for cereal-based systems in the savannas of West Africa*. In: Fatokun C. A., Tarawali S. A., Singh B. B., Kormawa P. M., Tamo M. (eds). *Challenges and Opportunities for Enhancing Sustainable Cowpea Production*. International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, Pp 252–266.
- Caswell, G. H. (1981). Damage to stored cowpea in the Northern part of Nigeria. *Samaru Journal of Agricultural Research Vol. 1: 11-19.*

- Catalogue of Crop Varieties Released and Registered in Ghana (CCVRRG), (2015) *1: 2015*.
- Centro Internacional de Agricultura Tropical (CIAT), (1986). *Main Insect Pests of Stored Beans and Their Control*: A Study Guide, Series 04EB-05.03, Apartado Aéreo 6713; CIAT (Centro Internacional de Agricultura Tropical): Cali, Colombia, 1986.
- Coetzee, J. J. (1995). *Cowpeas: A traditional crop in Africa*. Africa crops info. 95 leaflet. Vegetables and ornamentals plant Institute & the grain crops institute, Agricultural research council, Pretoria, South Africa.
- Cope, J. M. and Fox, C. W. (2003). Oviposition decisions in the seed beetle, *Callosobruchus maculates* (Coleoptera: Bruchidae): effects of seed size on super parasitism. *Journal of Stored Products Research 39(4): 355-65.*
- Crops Research Institute (CRI). (2006). Cowpea production guide: Introduction to cowpea production. *Retrieved from http://www.cropsresearch.org/publications/pdf/cowpea_Introduction.pdf. (Accessed on: 02/05/2017).*
- Council for Sientific and Indutrial Research-Savanna Agricultural Research Institute (CSIR-SARI) Annual Report (2013). Effective farming systems research approach for accessing and developing technologies for farmers. *CSIR-Savanna Agricultural Research Institute (SARI) Tamale, Ghana. Pp367.*

- Damte, T. and Dawd, M. (2003). *Chickpea, lentil and grass pea insect pest research in Ethiopia: A review*. In *Food and Forage Legumes of Ethiopia: Progress and Prospects*. Proceedings of a Workshop on Food and Forage Legumes, Addis Ababa, Ethiopia, 22–26 September 2003;
- De, D. N. (1974). *Pigeon pea*. In: *Evolutionary studies in World Crops: Diversity and change in the Indian subcontinent*. Educational Journal of Hutcbineon, Cambridge University Press.
- De Candolle, A. (1886). Origin of cultivated plants 2nd edition. Reprinted (1959), *Hafner Publisbing Co.*
- Decelle, J. (1981). *Bruchidae related to grain legumes in the perspectives*. Biology survey of Canada Manograph Service 1:439.
- Desroches, P. Elshazly, E. Mandon, N. Duc, G. Huignard, J. (1995). Development of *Callosobruchus chinensis* (L.) and *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae L.) in seeds of Vicia faba differing in tannin, convicine and vicine Contents. *Journal of Stored Product Research 1995 31:83-89.*
- Devi, M. B. Devi, N. V. (2014). Biology and morphometric measurement of cowpea weevil, *Callosobruchus maculatus* (F.) (Coleoptera: Chrysomelidae) in green gram. *Journal of Entomology and Zoology Studies 2 (3): 74-76.*
- Dick, K. and Credland, P. P. (1984). Egg production and development of three strains of *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *Journal of Stored Product Research Vol. 20: 221-227*. IN; Wright A. W.

(1986). Fecundity and oviposition behaviour of the cowpea seed beetle, *Callosobruchus maculatus* (Fabricius). A thesis submitted to the University of London for the degree of Doctor of Philosophy. *Department of Zoology, Royal Holloway and Bedford New College. Published by ProQuest LLC (2016). Pp327.*

- Dimetry, N. Z. El-Gengaihi, S. Abd-el-Salam, A. M. E. (2007). Protection of stored cowpea from *Callosobruchus maculatus* (F.) attack by some plant extracts formulations in different storage sacks. *Kerba polonica 53(1): 71-80.*
- Dobie, P. (1974). The laboratory assessment of the inherent susceptibility of maize varieties to post-harvest infestation by *Sitophilus zea mais* Motsch (Coleoptera, Curculionidae). *Journal of Stored Product Research 10: 183-197.*
- Dobie, P. Greve, J. V. S. Hothi, K. and Kilminster, A. M. (1979). Inability of storage bruchidae to infest winged beans (*Psopho-carpus tetragonolobus*). *Entomologia Experimentalis et Applicata 26:168–174.*
- Dobie, P. (1981). The use of resistant varieties of cowpeas *Vigna unguiculata* (L.) Walpers to reduce losses due to post-harvest attack by *Callosobruchus maculatus* (F.). *Series Entomologia 19:185–192.*
- Dugravot, S. Sanon, A. Thibout, E. and Huignard, J. (2002). Susceptibility of *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) and its Parasitoid *Dinarmus basalis* (Hymenoptera: Pteromalidae) to Sulphur-

Containing Compounds: Consequences on Biological Control. *Environmental Entomology 31(3): 550-557.*

- Edde, P. E. and Amatobi, C. A. (2003). Seed coat has no value in protecting cowpea seed against attack by *Callosobruchus maculatus* (F.). *Journal of Stored Product Research 39: 1-10.*
- Effowe, T. Q. Amevoin, K. Nuto, Y. Mondedji, D. and Glitho, I. A. (2010). Reproductive capacities and development of a seed bruchid beetle, *Acanthoscelides macrophthalmus*, a potential host for the mass rearing of the parasitoid, *Dinarmus basalis*. *Journal of Insect Science 10(129):1-14.*
- Egbadzor K. F., Yeboah M., Offei S. K., Ofori K. and Danquah E. Y. (2013). Farmers' key production constraints and traits desired in cowpea in Ghana. *Journal of Agricultural Extension and Rural Development 5(1): 14-20.*
- Egwurube, E. Magaji, B.T. and Lawal, Z. (2010). Laboratory evaluation of neem (*Azadirachta indica*) seed and leaf powders for the control of Khapra beetle, *Trogoderma granarium* (Coleoptera: Dermestidae) infesting groundnut. *International Journal of Agriculture and Biology 12 (4): 638–640.*
- Ekeh, F. N. Oleru, K. I. Ivoke, N. Nwani, C. D. and Eyo, J. E. (2013). Effects of Citrus sinensis Peel Oil on the Oviposition and Development of Cowpea Beetle *Callosobruchus maculatus* (F.) (Coleoptera: Chrysomelidae) in Some Legume Grains. *Pakistan Journal of Zoology 45(4): 967-974.*

- Ewedairo, B. I. Osipitan, A. A. Pitan, O. R. and Adebisi, M. A. (2015). Influence of maize grain hardness and phenol content on the resistance of some maize varieties to infestation by larger grain borer, *Prostephanus truncatus* (Horn) (Coleoptera: Bostrichidae). *Nigerian Journal of Entomology 31: 93-102.*
- Fatemeh, K. Ali, A. T. Yaghoub, F. and Samira, F. (2009). A Comparative Study on the Effect of Four Leguminous Species on Biological and Population Growth Parameters of *Callosobruchus maculatus* (F.) (Col.: Bruchidae). *Advances in Environmental Biology 3(3): 226-232.*
- Fatima, S. M. Usman, A. Sohail, K. Afzaal, M. Shah, B. Adnan, M. Ahmed, N. Junaid, K. Ali Shah, S. R. and Inayat-ur-Rahman, (2016). Rearing and identification of *Callosobruchus maculatus* (Bruchidae: Coleoptera) in Chickpea. *Journal of Entomology and Zoology Studies. 4(2): 264-266.*
- Fawki, S. Amany, S. K. Hoda, M. Abdel, F. Mohamed, A. H. Mona, I. M. and Dalia, A. M. S., (2012). Physical and biochemical basis of resistance in some cowpea varieties against *Callosobruchus maculatus* (F.). *Egyptian Journal of Pure and Applied Science 2012: 051-061.*
- Fox, F. W. and Young, M. E. N. (1982). *Food from the Yield*. Delta Books, Johannesburg, South Africa. pp 197.
- Fox, C.W. (1993). A quantitative genetic analysis of oviposition preference and larval performance of two host in the bruchid beetle, *Callosobruchus maculatus* (F.). *Evolution 47(1): 166-175.*

❖ Fox, C. W. and Reed, D. H. (2010). Inbreeding depression increases with maternal age in a seed-feeding beetle. *Evolutionary Ecology Research. 12(8), 961-72.*

❖ Fox, C. W. and Reed D. H. (2011). Inbreeding depression increases with environmental stress: an experimental study and meta-analysis. *Evolution, 65(1): 246-58.*

❖ Francis, A. K. Joseph, O. D. Ahmad, A. Emmanuel, H. Y. B. (2009). *Assessment of the Polytank for Fumigation and Storage of Cowpea.* MSc. Thesis, Faculty of Mechanical and Agricultural Engineering College of Engineering Kwame Nkrumah University of Science and Technology, Kumasi.

❖ Glitho, I. A. Tchamoou, K. S. and Amevoin, K. (1998). Dynamique des populations de *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae) déprédateur du niébé *Vigna unguiculata* (L.) Walp. en présence ou en absence des parasitoïdes dans les greniers expérimentaux. *Bulletin de L'IFAN, Cheik Anta Diop 49 (A): 197–211.*

❖ Golob, P. Moss, C. Devereau, A. Goodland, A. D. Andan, F. H. Atarigya, J. and Tran, B. M. D. (1999). Improvements in the storage and marketing quality of grain legumes: Final Technical Report, NRI Report 2417, Project R 6503. Natural Resources Institute University of Greenwich Chatham Maritime Kent, UK.

- Gómez, C. (2003). *Cowpea Post-Harvest Operations in Developing Countries.* Food and Agriculture Organization of the United Nations (FAO), Managua, Nicaragua. *Pp 84.*
- Gómez, C (2004). *Cowpea: Post-Harvest Operations*. Food and Agriculture Organization of the United Nations (FAO), Rome, Italy, Pp71.
- Haile, A. (2006). On-farm storage studies on sorghum and chickpea in Eritrea. *African Journal of Biotechnology 5:1537-1544*.
- Hina, H. K. Sarwar, M. and Lohar, M. K. (2015). Repellence Activity of Plant Oils against Red Flour Beetle Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) in Wheat. *International Journal of Animal Biology 1 (3): 86-92.*
- Huis, A. V. (1991). Biological methods in bruchid control in the tropics: a review. *Insect Science and Its Application 12: 87-102*.
- Ignacimuthu, S. (1999). Protein antimetabolites in legume seed defense. *Indian Journal of experimental biology 37: 215-222.*
- Iloba, B. N. Umoetok, S. B. A. and Keita, S. (2007). The biological control of the *Callosobruchus maculatus* (Fabricius) by *Dinarmus basalis* (Rendani) on stored cowpea *Vigna unguiculata* (L.) Walp. seeds. *Research Journal of Applied Sciences 2(4): 397-399.*
- International Grain Legume Information Center (IGLIC), (1987). Cowpeas (*Vigna unguiculata* L. Walp): Abstracts of world literature. *International Institute of Tropical Agriculture (IITA) Ibadan 5: 1983 - 1985. Pp164.*

- International Institute of Tropical Agriculture (IITA) (1982). Cowpea Production Training Manual. *International Institute of Tropical Agriculture (IITA) Manual Series No.11, Pp 203.*
- International Institute of Tropical Agriculture (IITA). (1993). *Annual report of the International Institute of Tropical Agriculture. pp. 56-80*. IITA, Ibadan, Nigeria.
- International Institute of Tropical Agriculture (IITA) (2010). *Fifth World Cowpea Conference 2010 held between 27th September to 1st October, 2010.* Palm Beach Hotel, Saly, Senegal.
- Jackai, L. E. N. and Daoust, R. A. (1986). Insect pests of cowpea. *Annual Review of Entomology 38: 95-119.*
- Jackai, L. E. N. and Asante, S. K. (2003). A case for the standardization of protocols used in screening cowpea, *Vigna unguiculata* for resistance to *Callosobruchus maculatus* (Fabricius) (Coleoptera: Bruchidae). *Journal of Stored Product Research 39: 251-263.*
- Jaloux, B. Sanon, A. Huignard, J. and Monge, J. P. (2004). Interspecific relationships between the solitary ectoparasitoid, *Eupelmus vuilleti* (Crw.) (Eupelmidae), and Its Sympatric Species, *Dinarmus basalis* (Rond.) (Pteromalidae), in the Presence of Their Host, *Callosobruchus maculatus* Pic (Coleoptera Bruchidae). *Journal of Insect Behavior 17: 793-808.*
- Jibrin, D. M. Abdullah, J. and Ibrahim, U. (2013). Evaluation of Some Plant Products for the Control of the Cowpea Weevil (*Callosobruchus*

maculatus). *American-Eurasian Journal of Agriculture And Environmental Science 13 (5): 673-676.*

- Johnson, C. D. and Romero, J. (2004). A review of evolution of oviposition guilds in the Bruchidae (Coleoptera). *Revista Brasileira de Entomologia 48(3): 401-408.*
- Jones, A. L. (1999). *Phaseolus bean: Post-harvest Operations*. Centro International de Agricultura Tropical (CIAT) *Pp. 25*. *www.cgiar.org/ciat*. (Accessed on 27/10/2017).
- Joseph, S. A. Ignatius, C. A. and Patience, D. N. (2016). Effect of biomaterial treatments on the storage stability and quality of cowpea. *American Journal of Life Sciences 4(6): 181-186.*
- Kananji, G. A. D. (2007). A Study of Bruchid Resistance and Its Inheritance in Malawian Dry Bean Germplasm. *African Centre for Crop Improvement (ACCI), School of Biochemistry, Genetics, Microbiology and Plant Pathology. Faculty of Science and Agriculture University of KwaZulu-Natal Republic of South Africa.*
- Kay, D. E. (1979). *Food Legumes*. Tropical Development and Research Institute, London, *UK.*
- Keneni, G. Bekele, E. Getu, E. Imtiaz, M. Damte, T. Mulatu, B. and Dagne, K. (2011). Breeding food legumes for resistance to storage insect pests: Potential and limitations. *Sustainability 3: 1399-1415.*
- Kingsolver, J. M. (2004). Handbook of the Bruchidae of the United States and Canada (Insecta, Coleoptera) Volum I. *United States Department of*

Agriculture. Agricultural Research Service. Technical Bulletin Number 1912.

- Kosini, D. and Nukenine, E. N. (2017). Susceptibility of Three Legume Species to *Callosobruchus maculatus* (Coleoptera: Chrysomelidae) Attack and Impact of Rearing Medium on Female Oviposition Host Preference. *Agricultural Research and Technology: Open Access Journal 8(1).*
- Lale, N. E. S. and Kolo, A. A. (1998). Susceptibility of eight genetically improved local cultivars of cowpea to *Callosobruchus maculatus* F. (Coleoptera: Bruchidae) in Nigeria. *International Journal of Pest Mannagement 44: 25-27.*
- Lambert, J. D. H. Gale, J. Amason, J. T. and Philogene, B. J. R. (1985). Bruchid control with traditionally used insecticidal plants *Hyptis spicigera* and *Cassia nigricans*. *Insect Science and Application 6: 167–168.*
- Langyintuo, A. S. Lowenberg-DeBoer, J. Faye, M. Lambert, D. Ibro, G. Moussa, B. Kergna, A. Kushwaha, S. Musa, S. Ntoukam, G. (2003). Cowpea supply and demand in West and Central Africa. *Field Crop Research 82:215-231*.
- Lowenberg-DeBoer, J. (1998). Bean/Cowpea CRSP West Africa. *Social Science Report April–Sept. 1998*. Cowpea market structure studies. www.entm.purdue.edu/entomology. *(Accessed on 15/05/2017).*
- Mahama, S. (2012). *Comparative Assessment of some Storage Technologies used for cowpea storage in the Nadowli District of the Upper West Region of Ghana*. MSc. Thesis Department of Horticulture,

Kkwame Nkrumah University of Science and Technology, Kumasi. Pp 75.

- Mano, H. and Toquenaga Y. (2008). Wall-making behavior in *Callosobruchus maculatus* (Coleoptera: Bruchidae). *Annals of the Entomological Society of America 101(2): 449-55*.
- Maina, Y. T. and Lale, N. E. S. (2004). Integrated management of *Callosobruchus maculatus* (F.) infesting cowpea seeds in storage using varietal resistance, application of neem (*Azadirachta indica* A. Juss) seed oil and solar heat. *International Journal of Agriculture and Biology 3:440–446.*
- Maina, Y. T. Mbaya, A. M. and Mailafiya, D. M. (2014). Evaluation of *Callosobruchus maculatus* (F.) susceptibility to neem (*Azadirachta indica* A. Juss) seed oil on different cowpea (*Vigna unguiculata* (L.) (Walp.) Cultivars. *Direct Research Journal of Agriculture and Food Science (DRJAFS) 2 (8): 179-186.*
- Mbaiguinam, M. Maoura, N. Biampambe, A. Bono, G. and Aladoumbaye, B. (2006). Effect of six common plant seed oils on survival, egg laying and development of cowpea weevil, *Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae). *Journal of biological sciences 6 (2): 420-425.*
- Mbata, G. N. (1993). Evaluation of susceptibility of varieties of cowpea to *Callosobruchus maculatus* (F.) and *Callosobruchus subinnotatus* (Pic.) (Coleoptera: Bruchidae). *Journal of Stored Products Research 22: 207-213*.

- Messina, F. J. (2004). How label are the egg-laying preferences of seed beetles. *Ecological Entomology 29 (3): 318-326.*
- Mkenda, P. A. and Ndakidemi, P. A. (2014). Pesticidal efficacy of four botanical pesticides on survival, oviposition and progeny development of bruchid, *Callosobruchus maculatus* in stored cowpea, *Vigna unguiculata*. *International Journal of Plant and Soil Science 3(12): 1504-1523.*
- Mochiah, M. B. Banful, B. Fening, K. N. Amoabeng, B. W. Offei Bonsu, K. Ekyem, S. Braimah, H. and Owusu-Akyaw, M. (2011). Botanicals for the management of insect pests in organic vegetable production. *Journal of Entomology and Nematology 3(6): 85-97.*
- Mofunanya, A. A. J. and Namgbe, E. E. (2016). Assessment of damage due to *Callosobruchus maculatus* (Coleoptera: Bruchidae) infestation on germination and nutrient quality of *Vigna unguiculata* L. (Walp). *IOSR Journal of Agriculture and Veterinary Science 9 (12): 96-101.*
- Mogbo, T. C. Okeke, T. E. and Akunne, C. E. (2014). Studies on the resistance of cowpea seeds (Vigna unguiculata) to cowpea weevil (*Callosobruchus maculatus*) infestations. *American Journal of Zoological Research 2(2): 37-40.*
- Mohamad, R. Monge, J. P. and Goubault, M. (2010). Can subjective resource value affect aggressiveness and con- test outcome in parasitoid wasps. *Animal Behaviour 80: 629-636.*

- Mohamad, R. Monge, J. P. and Goubault, M. (2011). Ago-nistic interactions and their implications for parasitoid species coexistence. *Behavioral Ecology 22: 1114-1122.*
- Monge, J. P. Dupont, P. Idi, A. and Huignard, J. (1995). The consequences of interspecific competition between *Dinarmus basalis* (Rond) (Hymenoptera: Pteromalidae) and *Eupelmus vuilleti* (Crw) (Hymenoptera Eupelmidae) on the development of their host population. *Acta Oe-cologia 16: 19-30.*
- Murdock, L. L. and Shade, R. E. (1991). Eradication of cowpea weevil (Coleoptera: Bruchidae) in cowpeas by solar heating. *American Entomology 37: 228–231*.
- Murdock, L. L. Seck, D. Ntoukam, G. Kitch, L. and Shade, R. E. (2003). Preservation of Cowpea Grain in Sub-Saharan Africa—Bean/Cowpea CRSP Contributions. *Field Crops Research* 82: 169–178.
- Muhammad, S. (2012). Assessment of resistance to the attack of bean beetle *Callosobruchus maculatus* (Fabricius) in chickpea genotypes on the basis of various parameters during storage. *Songklanakarin Journal of Science and Technology 34 (3): 287-291.*
- Mundi, A. D. Adamu, R. S. Ajayi, F. A. Bamayi, L. J. and Egwurube, E. A. (2012). Insecticidal evaluation of some botanical leaf powders on cowpea beetle *Callosobruchus maculatus* (F.) on stored bambara groundnut (*Vigna subterranea* (L.). *Verdcourt PAT June 8 (1): 52 -65.*

- Musa, A. K. and Adeboye, A. A. (2017). Susceptibility of some cowpea varieties to the seed beetle *Callosobruchus maculatus* (F.) (Coleoptera: Chrysomelidae). *Journal of Agricultural Sciences 62(4): 351-360.*
- Nalini, R. Usha, K. R. Rajavel, D. S. and Murali, B. R. K. (2012). Studies on relative resistance of cowpea genotypes to *Callosobruchus maculatus* (F.) (Coleoptera: bruchidae) both under field and laboratory condition. *International Journal of Advance Biological Research 2 (3):496-499.*
- Ntoukam, G. Murdock, L. L. and Shade, R. E. (2000). Managing insect pests of cowpea in storage, "Bean/Cowpea, Midcourse. *Research Meeting, Senegal. 2000; Pp 3 -4.* http://www.canr.msu.edu/oerseas/cowpea/proceed. *(Accessed on 23/01/2017).*
- Nwanze, K. F. Horber, E. and Pitts, C. W. (1975). Evidence for ovipositional preference of *Callosobruchus maculatus* for cowpea varieties. *Environmental Entomology 4: 409-412.*
- Nyamandi, P. and Maphosa, M. (2013). Evaluating the effects of indigenous cowpea weevil *Callosobruchus rhodesianus* management methods on stored cowpea. *International Journal of Agriculture and Crop Sciences 5 (22): 2761-2767.*
- Obopile, M. Masiapeto, K. and Gwafila, C. (2011). Variation in reproductive and developmental parameters of *Callosobruchus maculatus* (F.) reared on ten Botswana cowpea landraces. *African Journal of Biotechnology 10(63):13924-13928.*

- Ofosu-Budu, K. G. Obeng-Ofori, D. Afreh-Nuamah, K. and Annobil, R. (2008). Effect of phospho-compost on growth and yield of cowpea (*Vigna unguiculata*). *Ghana Journal of Agricultural Science 40(2):169-176*.
- Ojebode, M. E. Olaiya, C. O. Adegbite, A. E. Karigidi, K. O. and Ale, T. O. (2016). Efficacy of some plant extracts as storage protectants against *Callosobruchus maculatus* (F.). *Journal of Biotechnology and Biomaterial 6: 217.*
- Ojehomon, O. O. (1968). The development of the inflorescence and exteafloral nectaries of *Vigna unguiculata* (L) Walp). *Journal of West African Science Association 13: 93-114.*
- Olaitan, A. F. and Abiodun, A. T. (2011). Comparative toxicity of botanical and synthetic insecticides against major field insect pests of cowpea (*Vigna unquiculata* (L) Walp). *Journal of Natural Produce and Plant Resources 1 (3): 86-95.*
- Olajire, A. Gbaye, E. A. Oyeniyi and Olasehinde, B. O. (2016). Resistance of *Callosobruchus maculatus* (Fabricius) (Coleoptera: Bruchidae) Populations in Nigeria to Dichlorvos. *Jordan Journal of Biological Sciences 9(1): 41 – 46.*
- Oliveira, G. P. Pallaoro, D. S. Camili, E. C. and Dalmolin, Â. C. (2018). Physical and Bromatological Characteristics of Cowpea Varieties preferred by *Callosobruchus maculatus* (Coleoptera: Bruchidae). *Universidade Federal Rural do Semi-Árido Pró-Reitoria de Pesquisa e*

Pós-Graduação https://periodicos.ufersa.edu.br/index.php/caatinga. *(Accessed on 12/02/2017).*

- Olubayo, F. M. Port, G. R. (1997). The efficacy of harvest time modification and intercropping as methods of reducing the field infestation of cowpeas by storage bruchids in Kenya. *Journal of stored product research 33(4):271-276.*
- Onyido, A. E. Zeibe, C. C. Okonkwo, N. J. Ezugbo-Nwobi, I. K. Egbuche, C. M. Udemezue, O. I. and Ezeanya, L. C. (2011). Damage caused by the bean bruchid, *Callosobruchus maculatus* (Fabricius) on different legume seeds on sale in Awka and Onitsha markets, Anambah state, South Eastern Nigeria. *An International Multidisciplinary Journal, Ethiopia 5 (4): 116-123.*
- Osman, M. A. M. Mahmoud, M. F. and Mohamed, K. M. (2015). Susceptibility of Certain Pulse Grains to *Callosobruchus maculatus* (F.) (Bruchidae: Coleoptera), and influence of temperature on its biological attributes. *Journal of Applied Plant Protection (3): 9-15.*
- Organization for Economic Co-operation and Development (OECD) (2015). *Consensus document on the biology of cowpea* (*Vigna unguiculata* (L.) Walp.). Series on Harmonisation of Regulatory Oversight in Biotechnology No. 60. *Environmental Journal of Microbiology 48:44.*
- Ouedraogo, P. A. Sou, S. Sanon, A. Monge, J. P. Huignard, J. Tran, B. and Credland, P. F. (1996). Influence of temperature and humidity on populations of *Callosobruchus maculatus* (Coleoptera: Bruchidae) and its

parasitoid *Dinarmus basalis* (Pteromalidae) in two climatic zones of Burkina Faso. *Bulletin of Entomological Research 86: 695-702*.

- Oyewale, R. O. and Bamaiyi, L. J. (2013). Management of cowpea insect pests. *Schorlarly Acadermic Journal of Bioscience 1(5):217-226.*
- Panda, N. and Khush, G. S. (1995). *Host Plant Resistance to Insects*. CAB International in association with International Rice Research Institute (IRRI): Biddles Limited: Guildford, UK, 1995.
- Partnaik, N. C. Panda, N. and Dash, A. N. (1986). Effect of sowing date and cultivar on field infestation of the pulse beetle of pigeon pea. *International Pigeon pea News letter No. 5:44-46.*
- Piper, C. V. (1913). The wild prototype of the cowpea. *US Bureau of plant industry, soils and agricultural engineering circular No.124: 29-32.*
- Purseglove, J .M. (1968). *Tropical Crops*. Longmans Publishing Co.
- Porter, W. M. Pachie, K. O. Rawal, K. M. Wien, H. C. Williams, R. J. and Luse, R. A. (1975). "*Cowpea Gerrnplasm Catalog No.1*". IITA, PMB 5320, Ibadan, Nigeria pp 209.
- Prevett, P. F. (1961). Field infestation of cowpea (*Vigna unguiculata*) pods by beetles of the families bruchidae and Curculionidea in northern Nigeria. *Bulletin of Entomological Research 52: 635-646.*
- Production guidelines for Cowpeas (PGC), (2014). Resource Centre Directorate Agricultural Information Service. *Pretoria, South Africa, Pp16. Available at www.daff.gov.za*. (Accessed on: 01/02/2017).

- Purdue Improved Crop Storage (PICS) News letter, (2015). Volume 1 Issue 1. *Purdue University Department of Entomology 901 West State Street West Lafayette, Indiana, USA. Pp2.*
- Qazi, M. A. (2007). Development and monthly percent damage of *Callosobruchus Chinensis* L. *Pakistani Journal of Agricultural Research 20 :3-4.*
- Quass, C. F. (1995). Guidelines for the production of cowpeas. *National Department of Agriculture, Pretoria, South Africa.*
- Quin, F. M. (1997). *Importance of cowpea*. In Singh, B. B. Dashiell, K. E. Mohan Raj, D. R. and Jackai, L. E. N. Eds. *Advances in cowpea research.* Hong Kong, Colcorcraft. Pp 10-12.
- Rachie, K. O. and Roberts, L. M. (1974). Grain legumes of the lowland tropics. *Advances in Agronomy 26: 1-132.*
- Rachie K. O., (1972). *Improvement of food legumes in tropical Africa*. In: Milner, M. (ed.). Proceedings of a symposium sponsored by PAG on Nutritional Improvement of Food Legumes by Breeding held at the Food and Agriculture Organization. Rome, Italy, 3-5 July, 1972.
- Rachie, K. O. Rawal, K. Franckowiak, J. D. and Akinpe1u, M. A. (1975). Two out crossing mechanisms in cowpeas *Vigna unguiculata* (L) Walp. *Euphytica 24: 159-163.*
- Rachie, K. O and Rawal, K. (1976). Integrated approaches to improving cowpeas, *Vigna unguiculata* (L) Walp. *Technical Bulleting No.5 IITA 36pp.*

- Radha, R. and Susheela, P. (2014). Studies on the life history and ovipositional preference of *Callosobruchus maculatus* reared on different pulses. *Research Journal of Animal, Veterinary and Fishery Sciences 2(6): 1-5.*
- Reuben, S. O. W. M. Masunga, M. Makundi, R. Misango, R. N. Kilonzo, R. Mwatawala, M. Lyimbo, H. F. Ishengoma, C. G. Msuya, D. G. and Mulungu, L. S. (2006). Control of cowpea weevils (*Callosobruchus maculatus* L.) in stored cowpea (*Vigna unguiculata* L.) grains using botanicals. *Asian Journal of plant Sciences 5 (1): 91-97.*
- Sanginga, N. Dashiell, K. E. Diels, J. Vanlauwe, B. Lyasse, O. Carsky, R. J. Tarawali. S. Asafo-Adjei. B. Menkir, A. Schulz, S. Singh, B. B. Chikoye, D. Keatinge, D. and Ortiz, R. (2003). Sustainable resource management coupled to resilient germplasm to provide new intensive cereal–grain–legume–livestock systems in the dry savanna. *Agricultural Ecosystem and Environment 100:305–314.*
- Sanon, A. Ouedraogo, A. P. Tricault, Y. and Credland, P. F. (1998). Biological control of bruchids in cowpea stores by release of *Dinarmus basalis* (Hymenoptera: Pteromalidae) adults. *Environmental Entomology 27: 717-725.*
- Sariah, J. E. (2010). Enhancing cowpea (*Vigna unguiculata* L.) production through insect pest resistant line in east Africa. *Department of Agriculture and Ecology, University of Copenhagen. Pp100.*

- Sarwar, M. and Sattar, M. (2012). Appraisal of Different Plant Products against Trogoderma granarium Everts to Protect Stored Wheat. A Laboratory Comparison. *The Nucleus 49 (1): 65-69.*
- Sarwar, M. (2015). The Killer Chemicals for Control of Agriculture Insect Pests: The Botanical Insecticides. *International Journal of Chemical and Biomolecular Science 1(3): 123-128.*
- Schoonhoven, A. V. (1978). *Pest of stored beans and their economic importance in Latin America*. Paper to be presented in the Symposium on Tropical Stored Product Entomology, during the 15th international Congress of Entomology, August 19-27, 1976, Washington D. C. U.S.A.
- Shankar, U. and Abrol, D. P. (2012). Intergrated Pest Management in Stored Grains. *https://www.researchgate.net/publication/272172634*. *(Accessed on: 18/07/2017)*
- Silva, L. B. Sales, L. B. Oliveira, A. E. A. Machado, O. L.T. Fernandes, K. V. S. and Xavier-filho, J. (2004). The seed coat of *Phaseolus vulgaris* interferes with the development of the cowpea weevil [*Callosobruchus maculatus* (F.) (Coleoptera: Bruchidae)]. *Anais da Academia Brasileira de Ciências. Annals of the Brazilian Academy of Sciences 76(1): 57-65.* *www.scielo.br/aabc*. (Accessed on: 13/07/2017).
- Singh, B. B. Mohan-Raj, D. R. Dashiell, K. E. and Jackai, L. E. N. (eds.). (1997). Advances in cowpea research. *Copublication of International Institute of Tropical Agriculture (UTA) and Japan International Research Center for Agricultural Sciences (JIRCAS). UTA, Ibadan, Nigeria.*

- Singh, B. B. (2002). Challenges and orppotunities for enhancing sustainable cowpea production. In: Fatokun, C. A Tarawali, S. A. Singh, B. B Karmawa, P. M and Tamo, M. (eds). Resent genetic studies in cowpea. *International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, pp 3-13.*
- Singh, V. T. N. and Das, S. S. M. (2016). Chronobiological Management of Pulse Beetle *Callosobruchus maculatus* Fab. (Coleoptera: Bruchidae). *International Journal of Advances in Science Engineering and Technology 4(3): 117-121.*
- Simon, N. Moses, J. D. Zalkuwi, J. and Altine, J. M. (2015). Profitability analysis of cowpea production in Gombi local Government area of Adamawa State. *International Journal of Advances in Agricultural Science and Technology 2 (11):1-8.*
- Somta, P. Talekar, N. S. and Srinives, P. (2006). Characterization of *Callosobruchus chinensis* (L.) resistance in *Vigna umbellata* (Thunb.) Ohwi & Ohashi. *Journa of Stored Product Research* 42: 313-327.
- Soundararajan, R. P. 1. Chitra, N. Geetha, S. and Poorani, J. (2012). Biological control of bruchid *Callosobruchus maculatus* (F.) in blackgram. *Journal of Biopesticides 5: 192-195.*
- Steel, W. M. (1972). *Cowpeas in Nigeria*. Ph.D. Thesis, University of Reading.

- Stejskal, V. Aulicky, R. and Kucerova, Z. (2014). Pest control strategies and damage potential of seed-infesting pests in the Czech stores – a Review. *Plant Protection Science 50(4): 165–173.*
- Subramanyam, B. and Hagstrum, D.W. (1995). Sampling. In: Subramanyam, B. and Hagstrum, D. W. (eds). *Integrated Pest Management of Insects in Stored Products*. Marcel Dekker, New York.
- Swella, G. B. and Mushobozy, D. M. K. (2007). Evaluation of the efficacy of protectants against cowpea bruchids *Callosobruchus maculatus* (F.) on cowpea seeds (*Vigna unguiculata* (L.) Walp.). *Plant Protection Science 43: 68–72*.
- Tarawali, S. A. Singh, B. B. Gupta, S. C. Tabo, R. Harris, F. Nokoe, S. Fernández-Rivera, S. Bationo, A. Manyong, V. M. Makinde, K. and Odion, E. C. (2002). Cowpea as a key factor for a new approach to integrated crop–livestock systems research in the dry savannas of West Africa. In: Fatokun, C. A. Tarawali, S. A. Singh, B. B. Kormawa, P. M. Tamo, M. (eds). *Challenges and Opportunities for Enhancing Sustainable Cowpea Production.* International Institute of Tropical Agriculture (IITA), Ibadan, Nigeria, Pp 233–251.
- Talukder, F. (2009). Pesticide resistance in stored-product insects and alternative biorational management: A Brief Review. *Agricultural and Marine Sciences 14:9-15.*

- Tembo, L. Pungulani, L. Mataa, J. Sohati, P. H. and Munyinda, K. (2016). Developing cowpea and bean genotypes with tolerance to bruchid beetle. *Ruforum Working Document 14 (1): 879-883.*
- Thomas, M. B. and Waage, J. K. (1995). Integration of biological control and host plant resistance breeding for control of insect pests. *CTA-IAF. IIBC Seminar, 914 October 1995, Addis Ababa, Ethiopia.*
- Timko, M. P. Ehlers, J. D. and Roberts, P. A. (2007). Genome mapping and molecular breeding in plants. Pulses, Sugar and Tuber Crops. *Springer-Verlag Berlin Heidelberg 3. 2007.*
- Timko, M. P. Singh, B. B. (2008). Cowpea, a multifunctional legume, in: Moore, P. H. Ming, R. (Eds.), Genomics of tropical crop plants. *Springer, New York, pp. 227-257.*
- Tindal, H. D. (1983). *Vegetables in the Tropics.* Macmillan Press, London. pp181.
- Tiroesele, B. Thomas, K. and Seketeme, S. (2015). Control of cowpea weevil, *Callosobruchus Maculatus* (F.) (Coleoptera: Bruchidae), using natural plant products. *Open access Journal. Insects 6: 77-84.*
- Torres, E. B. Nóbrega, R. S. A. Júnior, P. F. Silva, L. B. Carvalho, G. S. Marinho R. C. N. and Pavan, B. E. (2016). The damage caused by *Callosobruchus maculatus* on cowpea grains is dependent on the plant genotype. *Journal of Science, Food and Agriculture 96:4276–4280.*
- Tran, B. M. D. and Credland, P. F. (1995). Consequences of inbreeding for the cowpea seed beetle, *Callosobruchus maculatus* (F.) (Coleoptera:

Bruchidae). *Biological Journal of the Linnean Society 56 483-503.* http://www.bmdtran.net/prof/CV/Tran. (Accessed on: 16/02/2017).

- Tuda, M. Rönn, J. Buranapanichpan, S. Wasano, N. and Arnqvis, G. (2006). Evolutionary diversification of the bean beetle genus *Callosobruchus* (Coleoptera: Bruchidae): Traits associated with stored-product pest status. *Molecular Ecology 15: 3541–3551.*
- Upadhyay, R. K. and Ahmad, S. (2011). Management strategies for control of stored grain insect pests in farmer stores and public ware houses. *World Journal of Agricultural Sciences 7 (5): 527-549*.
- Vavllov, N. I. (1951). The origin, variation, immunity and breeding of cultivated plants. *Ronald Press Company.*
- van Huis, A. van Alebeek, F. A. N. van Es, M. and Sagnia, S. B. (2002). Impact of the egg parasitoid *Uscana lariophaga* and the larval-pupal parasitoid *Dinarmus basalis* on *Callosobruchus maculatus* populations and cowpea losses. *Entomologia Experimentalis et Applicata 104: 289-297.*
- Van Rij, N. (1999). Production of cowpea in Kwazulu–Natal. Agriculture Update. *www.agriculture.kzntl.gov.za/agri-update/1999/update-5asp. pp:4. (Accessed on: 25/09/2017).*
- Wahedi, J. A. David, L. D. Edward, A. Mshelmbula, B. P. and Bullus, Z. (2013). Efficacy of seed powder and extracts of *Azadirachta indica* linn (meliaceae) at graded levels on adult *Callosobruchus maculatus* (F.)

(Coleoptera: bruchidae) in Mubi, North-Eastern Nigeria. *International Journal of Science Nature 4 (1):138-141.*

- Westphal, E. (1974). Pulses in Ethiopia, their taxonomy and agricultural significance. *Center for Agricultural Publishing, Wageningen.*
- Wright, A. W. (1986). Fecundity and oviposition behavior of the cowpea seed beetle, *Callosobruchus maculatus* (Fabricius). Phd. Thesis, Department of Zoology, Royal Holloway and Bedford New College, University of London.
- Yamane, T. (2013). Biorational control methods for protection of stored grain legumes against bruchid beetles. *Agricultural Sciences 4(12): 762-766.*
- Yusuf, A. U. Dike, M. C. Adebitan, S. A. and Ahmed, B. I. (2011). Comparative efficacy of seven plant products on the cowpea burchid, *Callosobruchus maculatus* (F.) development and damage. *Journal of Biopesticides 4 (1): 19 - 26 (2011).*

APPENDICES

Apendix 1. *F-Probabilities* for the effect of variety on damage and damage related parameters of *C. maculatus* on stored cowpea.

F-probability								
		Oviposition	Nº of insects emerged	Developmental period (days)	Damage grains	Grain weight loss	Grain viability	Susceptibility index
effect	df							
Variety	6	<.001	<.001	<.001	<.001	<.001	<.001	<.001

Appendix 2. ANOVA table for the number of eggs laid/seed (oviposition)

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.7160	0.2387	1.87	
Variety	6	24.4159	4.0693	31.87	<.001
Residual	18	2.2984	0.1277		
Total	27	27.4303			

Appendix 3. ANOVA table for percentage grain weight loss

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.792	0.264	0.14	
Variety	6	86.661	14.444	7.90	<.001
Residual	18	32.916	1.829		
Total	27	120.369			

Appendix 4. ANOVA table for median developmental period

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	0.7143	0.2381	0.74	
Variety	6	107.9286	17.9881	55.96	<.001
Residual	18	5.7857	0.3214		
Total	27	114.4286			

Appendix 5. ANOVA table for percentage grain damage

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	66.71	22.24	1.72	
Variety	6	2231.71	371.95	28.82	<.001
Residual	18	232.29	12.90		
Total	27	2530.71			

Appendix 6. ANOVA table for susceptibility index

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	25.9029	8.6343	23.33	
Variety	6	164.8650	27.4775	74.26	<.001
Residual	18	6.6603	0.3700		
Total	27	197.4282			

Appendix 7. ANOVA table for number of insects emerged

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	7603.14	2534.38	26.25	
Variety	6	17093.86	2848.98	29.51	<.001
Residual	18	1737.86	96.55		
Total	27	26434.86			

Appendix 8. ANOVA table for seed viability

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Rep stratum	3	160.71	53.57	1.40	
Variety	6	24417.86	4069.64	106.27	<.001
Residual	18	689.29	38.29		
Total	27	25267.86			