# VARIETAL RESISTANCE AND USE OF CRUDE PLANT EXTRACTS IN THE MANAGEMENT OF FIELD PESTS IN GREEN GRAM *(Vigna radiata)* IN MACHAKOS COUNTY, KENYA

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**DECLARATION**

This thesis is my original work and has not been presented for the award of a degree in any other University.

Date: 6 June 2023

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## DEDICATION

To my late dad, Philip Mulwa and family for their continued support and encouragement.

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## LIST OF ABBREVIATIONS

| | |
|---|---|
| ANOVA | Analysis of variance |
| IAGC | International Aphid Genomic Consortium |
| KALRO | Kenya Agricultural and Livestock Research Organization |
| KCSAP | Kenya Climate Smart Agricultural Project |
| LSD | Least significance difference |
| MoALF | Ministry of Agriculture, Livestock and Fisheries |
| NPK | Nitrogen, Phosphorous and Potassium |
| USA | Unites States of America |
| USAID | United States Agency for International Development |

## GENERAL ABSTRACT

Breeding has significantly improved drought tolerance in green gram but marked yield losses continue to emanate from field pest's damage. Important pests of green gram are pod borers, *Maruca testutalis* (Geyer), aphids, *Aphis gossypii* (Glover) and whiteflies, *Bemisia tabaci* (Gennadius). Management of these pests has partly been constrained by the limited understanding of crop traits that modulate their infestation. Continuous use of synthetic pesticides causes serious health and environmental consequences. To reduce these challenges, and lower the cost of production, farmers rely on indigenous knowledge to manage crop pests. Several plant species are known to have insecticidal properties against a range of insect pest. Despite growth on research, there is limited data on pesticidal plants and only a few of them have been commercialized for pest management hence remaining a small but growing component in crop protection. Field experiments were conducted in southeastern Kenya to evaluate a collection of old and new green gram varieties for tolerance to field pests, and to identify traits that confer resistance for objective one. The old varieties were KS20 and N26, both released in 1990s whereas the modern counterparts were Biashara, Karembo and Ndengu-Tosha. Evaluating the efficacy of four plant extracts of diverse species, including neem (*Azadirachta indica*), melia *(Melia volkensii)*, tick berry (*Lantana camara)* and garlic (*Allium sativum)* in the management of green gram field pests was also studied. Respective plant extracts were prepared and applied at 10mL/20L of water at seven days interval and compared to lambda-cyhalothrin which was applied at the rate of 5mL/20L of water as a standard check and untreated control. Results showed significant differences amongthe varieties in maturity, leaf area, leaf hair density, leaf moisture content and pod wall thickness. Earliness significantly reduced pest infestation, whereby KS20 matured early while N26 was late,and the new varieties were intermediate. Leaf area ($R^2$ = 0.52) and leaf moisture content ($R^2$ = 0.71) positively correlated with pest infestation while leaf hair density ($R^2$ = 0.47) and pod wall thickness ($R^2$ = 0.58) showed a negative association with pod borer and aphid counts. Crops applied with tick berry and melia plant extracts showed significantly higher number of pod borers,aphids, whiteflies and natural enemies of about 70 -80% compared to neem and garlic which showed 40-50% of the pest numbers. Pod damage was highest in melia and tick berry ranging from 70-90% and lowest in neem and garlic with a range of 36-63% accordingly. Crops sprayed with garlic extract out-yielded (2.8 t/ha) the other treatments while those applied with melia recorded the least grain yield (2.6 t/ha). However, objective one results did not reveal any particular traitsthat associated with either the old or new varieties, which implied that breeding of green gram in Kenya has not selected for tolerance to field pests. Nonetheless, green gram breeding programs could select for early maturity, open plant canopy, pubescent leaves and thicker pod walls to reduce field pests' infestation. On objective two, the four plant extracts offered an effective control of keypest species, especially neem and garlic extracts, that was comparable in terms of yield harvested to the synthetic pesticide. Overall, the plant extracts had lower negative impact on the beneficial organisms compared with the synthetic insecticide. Results of this study imply that integrated field pest management practices in green gram could deploy varieties with morphological traits that impair pest infestation as well the incorporation of pesticidal crude plant extracts.

# CHAPTER ONE: INTRODUCTION

## 1.1 Background information

Green grams, also referred to as mung bean (*Vigna radiata* L. Wilczek) is a legume crop grown for its edible seeds and is known to have originated in India, from where it later spread to other Asian countries and then Africa (KyungGeun *et al.*, 2004). In Kenya, the crop is mostly grown in parts of the Eastern and Northern areas and commonly grown in the drier areas due to its tolerance ability to drought (USAID, 2013). Green gram is gaining popularity and is been grown by small scale farmers in the dry areas both as food and cash crop due to its high nutritive and yield levels (Karimi *et al.*, 2019). The crop is on at least 6 million hectares worldwide which accounts for 8.5% of global pulse production (Nair *et a*l., 2013). In Kenya, green grams are grown on an average of 260,000ha, mostly in the Arid and Semi-arid areas (MoALF, 2017).

Green gram seeds can be cooked or milled, eaten either as split or whole and the milled flour and sometimes used as fodder or as a cover crop (Infonet Biovision, 2019). The seed is a good source of proteins, iron, phosphorous, carbohydrates, fiber and minerals. Green gram seeds are traditionally known to cure paralysis, coughs, fevers and liver problems (Mogotsi, 2006) and a source of income to Kenyan growers (Wambua *et al.*, 2017). Varieties N26 and KS20 are the two varieties, mostly grown in Kenya and within East Africa regions where green gram thrives well due to its agro-ecological suitability (MoALF, 2016).

Green gram production is faced with a range of abiotic and biotic constraints that significantly reduce yield potential (Chauhan *et al.*, 2013). Drought and low soil fertility stand out as the most important abiotic constraints to green gram yield. Green gram is also highly susceptible to waterlogging. Economically important biotic constraints include diseases, particularly bacterial and fungal infections, as well as field and storage pests. The most destructive field pests of green gram are pod borers, aphids, whitefly and bean fly while the storage pests are mostly the bruchids.

The management of field pests encompasses cultural methods, physical and chemical control, biological agents and the integration of two or more control methods. One of the important components of cultural control is the choice of variety. Breeding efforts are geared towards the development of early maturing varieties that escape pest attack as well as the deployment of pest tolerance mechanisms. Early maturing varieties and planting date adjustment ensures that the crop escapes pest attack because by the time the first instar caterpillar begins to feed the crop is almost podding hence the pest has less time for feeding (Chauhan *et al.*, 2013).

Use of synthetic pesticides has led to serious environmental consequences, food safety concerns, development of insecticide resistance and higher cost of production. There are a range of plant extracts that have historically been shown to exhibit insecticidal properties. Plant extracts do have adverse effects, and they are cheap and locally available to farmers. Indeed, farmers have long-standing indigenous knowledge on the use of crude plant extracts in managing both field and storage pests. The common modes of action of plant extracts are repulsion effect, reduced fecundity, mobility and feeding activity by the insect (Patil *et al.*, 2017).

Recent trends in green gram losses and crop failure can be attributed to severe field pest attacks and inadequate information on the pests, hence it is important to determine the various genotypes of green grams that are less prone to field pest infestation. Understanding the preference to or rejection of certain varieties in terms of varietal morphology by the various pod borers on selected genotypes is an important step towards determining genetic superiority of some germplasm.

## 1.2 Statement of the problem

Historically, improvement of green gram yield has focused more on the development of drought tolerant and early maturing varieties. The older green gram varieties in Kenya are KS20 and N26 but recently Kenya Agricultural and Livestock Research Organization (KALRO) has released Biashara and Karembo which are early maturing. In addition, there is a range of pre-release materials that are at advanced stages of release as seed such as variety Ndengu-Tosha. Little attention has been paid on the development of pest and disease tolerant varieties potentially due to the poorly developed green gram seed systems. Nonetheless, as the crop gains importance, both in food and income security, the seed systems are undoubtedly growing strong. To sustain the growing demand for green gram, it is important to improve yield through reduced pest damage. However, it is only partially known how the current green gram varieties escape or tolerate attack by field pests. Early maturity is a key avoidance mechanism to escape pest attack while morpho-physiological traits could significantly modify the pest behavior. In soybean, higher leaf hair density has been shown to reduce aphid population (Ihsan-ul-Haq *et al*., 2003). Other important attributes that significantly affect pest population include moisture content, leaf area and canopy density. It is therefore important to characterize the current green gram varieties in Kenya for morphological and physiological traits that might confer tolerance to pod borers, aphids and white flies.

Environmental concerns arising from the use of synthetic pesticides has been on the rise due to the pesticide negative impacts on the environment hence the need to use alternative methods through use of pesticidal crude plant extracts. Plant extracts have a long history in the management of pests in diverse crops and communities. Frequently used plant extracts in southeastern Kenya are neem (*Azadirachta indica*), garlic (*Allium sativum*), tick berry (*Lantana camara)*, *Melia volkensii*, *Mexican marigold*, among others but their efficiency against economically important field pests of green gram is notknown.

## 1.3 Justification of the study

In addition to drought and low soil fertility, low yields in green gram arise from damage by field pests. Field pests have been shown to contribute up to 60% yield loss in green gram depending on pest species and stage at which the crop is attacked. Insecticidal sprays in the management of field pests are expensive and often lead to environmental consequences. To reduce pest damage and increase yield, sustainable approaches such as varietal resistance and sprays from plant extracts are urgently required. However, the mechanisms of resistance to field pests in green gram and insecticidal efficiency of local plant extracts is only poorly understood. Understanding the avoidance and morpho-physiological mechanisms that confer resistance to key field pests in green gram would inform breeding programs that have previously concentrated on drought tolerance. Findings of this study will inform farmers and stakeholders on green gram varietal resistance to pod borers, aphids and whiteflies, and decipher the underlying mechanisms. In addition, the study will profile the efficacy of some of the locally available plant extracts in the management of field pests in green gram.

## 1.4 Objectives

The broad objective of this study is to reduce the infestation of green gram by field pests by deploying tolerant varieties and the use of efficacious crude plant extracts. The specific objectives of this study are:

(i) To evaluate selected green gram varieties for tolerance to field pests, and to identify traits that confer resistance

(i) To determine the efficacy of selected crude plant extracts in the management of pod borers, aphids and whiteflies in green gram

## 1.5 Hypotheses

(i) Green gram varieties do not show differences with regard to resistance to infestation by pod borers, aphids and whiteflies.

(ii) Plant extracts are not effective in the control of pod borers, aphids and whiteflies in green gram

# CHAPTER TWO: LITERATURE REVIEW

## 2.1 Importance of green gram in Kenya

In Kenya, green gram is abundantly grown by small scale farmers and can withstand and escape drought through curtailing the flowering and maturation period (Swaminathan *et al.*, 2012). The crop is suitable for the arid and semi-arid parts of Kenya covering 80% of Kenya's green gram production growth coverage (Herrero *et al.*, 2010). Green grams thrive well in drier areas of the lower eastern Kenya (USAID, 2013). The crop's tolerance to drought has made it to be grown in different soil types and climatic conditions with a well-structured rooting system that helps in acquiring water to improve and sustain its yield (Kumar and Sharma, 2009). Green gram crop has multiple benefits such as food security, fodder for livestock and source of income despite the low yields (Wambua *et al.*, 2017). The crop can serve as possible source of non-animal protein as used in some parts of East Africa during Rift Valley fever outbreak (Machocho *et al.*, 2012).

## 2.2 Green gram production trends in Kenya

Kenya is the leading producer and consumer within the East African countries (MoALF, 2017). The crop is mostly grown by small scale farmers in the driers regions (Machocho *et al.*, 2012). Machakos, Kitui, Makueni and Tharaka-Nthi are the major counties where green gram production is successful due to their climatic characteristics (USAID, 2013). In Africa, green gram is grown in more than 40 countries, central, East, South and West Africa (Infonet Biovision, 2019).

India is globally the major producer and consumer of green grams in the world with a 25 per cent global production and 15 percent consumption. Green gram is the third most important pulse crop in India, contributing to 8 per cent of total pulse crop in the country (Khairnar *et al.*, 2019) however, green grams production in India is 18.1 million tones, a higher import demand of about 24 million tons per year is reported (Vaibhav *et al.*, 2018).

## 2.3 Constraints to green gram production in Kenya

Low green gram yield can be attributed to both abiotic and biotic factors that affects the green gram yield production, the biotic factors include pests and diseases while the abiotic factors are the climatic conditions and poor agronomic practices (Machocho *et al.*, 2012). In most farms reports of green gram yield per acre is between 30-416 kilograms compared to 300-1500 kilograms per acre as recommended by research (Karanja *et al.*, 2006). Diseases including bacterial, viral and fungal diseases reduce the crop yield (Swaminathan *et al.*, 2012). Diseases and pests are the major biotic factors. Bacterial diseases like damping off, bacterial bean blight and bean rot, fungal disease like powdery mildew, halo blight and wilt and the viral diseases, the yellow mosaic disease and leaf crinkle virus (War *et al.*, 2017).

Pests, both field and storage pests, affect green gram, the field pest include the bean fly, thrips, whiteflies (*Bemisia tabaci),* aphids (*Aphis gossypii*) and the pod borers *(Maruca testutalis*), for example*, Maruca testutalis*, whose caterpillar bore into the stem and pods leading to wilting and stunting, sometimes prone to attack by secondary pathogens (Swaminathan *et al.*, 2012). The aphids through their feeding suck the plant sap leading to deformation, discoloration, stunted growth as well acting as vectors to plant viruses (Morita *et al.*, 2007)**.** The whiteflies cause damage to the crop through sucking of the plant sap, transmission of plant viruses and production of honeydew that affects photosynthetic process leading to reduction in yields (Prabhaker *et al.*, 2005). Both aphids and whiteflies have modified mouthparts where they suck the plant sap hence damaging the plant through yield reduction and plant weakening leading to death. Bruchids are the major stored legumes pests, they attack the crop during and after harvesting causing devastating losses if not controlled and also depending on the storage environment.

## 2.4 Advances in the breeding of green gram

Breeding knowledge and information on biotic and abiotic factors in green grams at the crop development stage is necessary in identification of tolerant traits expressed at each stage. The plants screening resistance depending on the number of shoots before flowerings and egg numbers per plant at the early stages of the plant (Oghiakhe *et al.*, 1992). These practices are quite expensive and pose both health and environmental challenge and not affordable to the poor farmers. Breeding has been done towards achieving early maturing and drought tolerant green gram varieties with a higher yield potential, for example, Karembo and Biashara that were released by KALRO take less than 90 days to mature. It involves use of the crop's morphological traits that interferences with the pest behaviors, for instance, leaf hairs that reduces the pest movement. Some agronomic practices like intercropping green gram with maize and sorghum and growing the crop under low light intensity in order to reduce light reaching the soils reduces evaporation and transpiration rate from the crop hence minimizing water loss which improves the agronomic performance of the crop (Masaku, 2019). Breeding against pests attack, interaction between the plant and pest should be well understood, screening insect population, adjustment of planting dates, inflorescence tagging and grouping of plants accordingto maturity and their height (Sharma *et al.*, 2005)

## 2.5 Economically important field pests of green gram

### 2.5.1 Pod borers

Pod borers are pests of most legumes and attacks the leaves, flowers and pods causing a major reduction of yields. They are various pod borers that are known to attack the crop including spotted pod borer, spiny pod borer and with spotted and spiny pod borer being the major pod borers of green grams (Srivastava and Singh, 2017).

Spotted pod borer attacks tender leaves, flowers and the pods, during feeding the cluster togetherand forms a webbing like structure in leaves and flowers while in pods they bore inside the podscausing a major yield reduction (Ganapathy and Durairaj, 2000). The attacked pods have large holes due to feeding of the pest as they bore into the seeds and selectively feeds on the growingand reproductive part of the plant (Banu *et al.*, 2007).

Spiny pod borer *(Helicoverpa armigera*) is a polyphagous pest that feeds on beans, chickpea, lablab and also cotton crops (Sarwar *et al*., 2009). Spiny pod borer maybe destructive as it feeds from vegetative to pod formation growth stage of the crop (Patil *et al*., 2017). The attacked crop leaves have large irregular holes due to feeding by the pest and are known to selectively feeds on the growing and reproductive part of the plant (Banu *et al.*, 2007).

### 2.5.2 Aphids

Aphids belong to family *Aphididae*. They are phytophagous pierce- sucking pests that feed on more than 4000 food crops with over 100 aphid species. Aphids attack agricultural crops and feed on their phloem sap as they suck leading to stunted growth, deformation of leaves, buds and flowers as well as aids in transmission of viral diseases. Their life cycle is complex, it involves both asexual and sexual reproduction system, they might also be winged or wingless and each of allis well adapted to different ecological zones (IAGC, 2010).

Asexually, females reproduce living young without fertilization or through pathogenesis as opposed to eggs with adults having two pairs of membranous wings where they are able to fly to new plants throughout summer (Simon, 2011). The female eggs and they produce wingless female nymphs which are very similar to adults and through molting the nymph grows to adults. These nymphs feed on shoots and leaves where they hatch when buds' sprouts, they molt to mature adults and produce new offspring (Trionnaire *et al*., 2008). Sexually, winged females and male are produced in summer where they mate and produce eggs that survive the winter producing a new generation of wingless offspring. Aphids are known either a simple or complex life histories, some aphids may use a single species host plant to complete their life cycle while other species needs two host plant species to complete their life cycle (IAGC, 2010).

The legume aphid *(Aphis craccivora*) commonly attacks the green gram. Both the adult and nymphs feed on young plants, young leaves, stems and pods of green grams. Aphid infestation exhibits several symptoms on the plants, the attacked leaves appear twisted, deformation and discoloration of the plants. Excretion of honeydew and sooty molds on the leaves is very common and is known to affects the photosynthetic process of the plant reducing the quality and quantity of the crop (Zia *et al*., 2011). Aphids acts as viral disease vector, aphid borne mosaic virus (Morita *et al*., 2007) which reduces the yields and under severe infestation the crop may die. The legume aphid, *Aphis craccivora,* causes major losses primarily infesting the seedlings although a larger population infests the leaves, flower buds, flowers and pods

### 2.5.3 Whiteflies

Whiteflies (*Bemisia tabaci*), are phytophagous pests belonging to order Homoptera. They are responsible for host plant attack and are important insect pests and attack a variety of agricultural crops with over 156 species. They are major pests and major vectors in virus diseases transmission and are known to disperse over long distances through flying and being carried by the air currents (Legg, 2010).

Whiteflies have six stages, which consist of egg, four nymphs and the adult (Walker *et al.*, 2010). Eggs are laid on the lower side of young leaves and are laid over the leaf and hatch into first instars which moves along to find a feeding site and begins to feeds throughout their immature stage. Second to fourth instars are the nymphs and look like small insects, the nymph colour vary from yellow to black depending on the species. Fourth instars, are referred to as 'pupa' because mobile adults emerge after the development is complete (Patil *et al.*, 2017).

Whiteflies are reported to transmit different plant viral diseases, for example mosaic and leaf curl in green gram (Swaminathan *et al.*, 2012). Whiteflies use their modified mouthparts to suck and damage the plant leading to yield reduction and plant weakening or death under severe infestation through excretion of honeydew with adults producing more honeydew than nymphs (Prabhaker *et al.*, 2005). The honeydew covers the crop foliage and fruits where the surface becomes sticky and black and can lead to saprophytic fungal species occurring reducing the photosynthetic process hence low yield.

## 2.6 Management of field pests of green gram

Field pests can be management and controlled in various ways with the aim of yield improvement. Breeding for insect resistance and crop tolerance is one the effective ways to manage pest including manipulation of plant population and the adjustment of planting dates, intercropping for interference with the pest's life cycle and weed control that can act as alternate host of the pest among others (Oghiakhe *et al.*, 1992). Breeding for insect resistance involves identification of resistance source, screening plant against major pests, adjustment of planting date, augmentation of pest and plant phenology determination (Sharma *et al.*, 2005). Adjusting the planting date includes early or late planting, early planting is commonly practiced because it ensures the crop grows early hence escaping pest infestation. Plant phenology determines the growth stage duration for the plant in order to compare with the pest life cycle especially the caterpillars (Sharma *et al.*, 2005).

Plant extracts can be used for insect control and help obtain sustainable production, food security and safety, they exhibit insecticidal activity against the pests (Elechi and Ekemezie, 2020). Plant extracts exhibit insecticidal effects against the pest, they interference with the pest's behavior like feeding, oviposition and movement. They also act as repellants where the pests cannot survive in crops treated with plant extracts like *Melia volkensii* and *Lantana camara* that acts as good pest repellants. They are known to reduce pest resistance and tolerance, environmentally safe, available and have diverse effects on pest including stomach indigestion, mobility inhibition, reduced fecundity.

## 2.7 Important pesticidal crude plant extracts

Most plants are convenient to be used by farmers due to their abundance within their farms, familiarity and farmers have a considerable existing knowledge and efficacy and safety too about the plants (Stevenson *et al.*, 2012). Important plants with pesticidal properties among farmers in eastern Kenya are tick berry **(***Lantana camara),* tree marigold *(Tithonia diversifolia),* Melia *(Melia volkensii),* Black jack *(Bidens pilosa),* Fish bean *(Tephrosia vogelii)* Garlic *(Allium sativum)* and Neem *(Azadirachta indica).* They can be derived from plant parts such as the leaves, flowers, seeds or in bulbs as for garlic where they are prepared into concentrations that can be used f or pests management (Rahman *et al.*, 2016)**.** Most of the plant extracts used as pesticides are more viable, effective and eco-friendly compared to the synthetic pesticides, they are also known to reduce environmental degradation, pest resistance, increase food security and production capabilities (Adeniyi *et al.*,2010).

Plant extracts are known to interfere with pest behaviors, oviposition, reproduction, growth and development, however. They ensure protection and conservation of non-target pests such as bees while contributing to better yields at low cost especially to small scale farmers (Tembo *et al.*, 2018). However, they are not very much effective due to efficacy variations and their low toxicity and persistence to the targeted pests (Grzywacz *et al.*, 2014) although, the need to decrease synthetic pesticide usage and enhance practices that promote environmental safety makes them more effective for environmental safety (Sola *et al.*, 2014)**.**

## 2.8 Interaction between pests and pesticides

Plants absorb pesticides into the system through leaves and roots where they move to other parts of the plant, some pesticide can have a contact or systemic mode of action. The active ingredients in pesticides can have unintended effects on the pests or other microbes associated with the pest. The effects can be either directly to the pests or indirectly through the crop or weeds within the surrounding, the pesticide may also be harmful to potential microbes that would act as natural enemies of the pest under control (Duke, 2018). Glyphosate used in weed control disrupts the shikimate pathway leading to stunting, loss of chlorophyll and tissue death in weeds which can also be observed in the nearby crop, this is because glyphosate is non-bio accumulate and has highly soluble in water (Duke, 2020).

Plants absorb pesticides into the system through leaves and roots where they move to other parts of the plant, some pesticide can have a contact or systemic mode of action. The active ingredients in pesticides can have unintended effects on the pests or other microbes associated with the pest. The effects can be either directly to the pests or indirectly through the crop or weeds within the surrounding, the pesticide may also be harmful to potential microbes that would act as natural enemies of the pest under control (Duke, 2018). Glyphosate used in weed control disrupts the shikimate pathway leading to stunting, loss of chlorophyll and tissue death in weeds whichcan also be observed in the nearby crop, this is because glyphosate is non-bio accumulate and has highly soluble in water (Duke, 2020).

## 2.9 Key active ingredients and mode of action of plant extracts

Plants used as botanicals have different active ingredients that affects the pest in various ways, some have repellant, ovicidal, antifeedant and toxic effects on the pests (Isman, 2008). Neem contain azadirachtin as the active ingredient, which is repellant in nature and causes high mortality, reduces oviposition and reproduction (Erdogan, 2012). Azadirachtin from neem contains hormone mimicking activities which interferences with the pest lifecycle hence inhibiting feeding and hatching as well as growth regulation (Kumar and Navaratnam, 2013). Tick berry leaves contains methanol that has insecticidal activity, contact toxicity and bioactive molecules (Dua *et al.*, 2010)**.** Methanol from the *Lantana camara* leaves interferes with the pest's nervous system, acts as feeding deterrent preventing the pest from feeding (Mpumi *et al.*, 2016)**.***Melia volkensii* leaves are known to contain volkensin and salannin compounds that prevents thepest from feeding, reduces oviposition, leads to stunting growth as well as decreased motility (Jaoko *et al.*,2020). Garlic**,** *Allium sativum,* contains alliin which is a sulfur containing compoundthat prevents the pest from feeding (Singh and Singh 2008).

# CHAPTER THREE: EVALUATION OF SELECTED GREEN GRAM VARIETIES FOR TOLERANCE TO FIELD PESTS AND IDENTIFICATION OF TRAITS THAT CONFER RESISTANCE


## 3.1 Abstract

Breeding has significantly improved drought tolerance in green gram but marked yield losses continue to emanate from field pests damage. Important pests of green gram are pod borers, *Maruca testutalis* (Geyer), aphids, *Aphis gossypii* (Glover) and whiteflies, *Bemisia tabaci* (Gennadius). Management of these pests has partly been constrained by the limited understanding of crop traits that modulate their infestation. Field experiments were conducted in southeastern Kenya to evaluate a collection of old and new green gram varieties for tolerance to field pests, and to identify traits that confer resistance. The old varieties were KS20 and N26, both released in 1990s whereas the modern counterparts were Biashara, Karembo and Ndengu -Tosha. Results showed significant differences among the varieties in maturity, leaf area, leaf hair density, leaf moisture content and pod wall thickness. Earliness significantly reduced pest infestation, whereby KS20 matured early while N26 was late, and the new varieties were intermediate. Leaf area ($R^2$ = 0.52) and leaf moisture content ($R^2$ = 0.71) positively correlated with pest infestation while leaf hair density ($R^2$ = 0.47) and pod wall thickness ($R^2$ = 0.58) showed a negative association with pod borer and aphid counts. However, results did not reveal any particular traits that associated with either the old or new varieties, which implied that breeding of green gram in Kenya has not selected for tolerance to field pests. Nonetheless, green gram breeding programs could select for early maturity, open plant canopy, pubescent leaves and thicker pod walls to reduce field pests' infestation.



*Keywords*: modern varieties, leaf hairs, maturity, pod borer, aphids

## 3.2 Introduction

Green gram, also referred to as mung bean, *Vigna radiata* (L. Wilczek) is a legume crop that is grown for its edible dry seeds and a source of low flatulence proteins. Green gram originated from India and has since spread to other continents, including Africa (KyungGeun *et al.*, 2004). The crop has a short life cycle and adapts well to drought due to its elaborate root system which enhances exploration for water and nutrients (Kumar and Sharma, 2009). Globally, the annual production of green gram is about 3 million tons from more than 6 million hectares under cultivation (Nair *et al.*, 2013). In Kenya, green gram is predominantly grown in the climatically marginal areas of eastern Kenya as food staple and cash crop (Kilimo Trust,2017, Karimi *et al.*, 2019).

In southeastern Kenya, farmers often obtain about 0.5 t/ha against a yield potential of 4 .5 t/ha. Yield potential is the yield of a crop when it is grown in its adapted environment with adequate supply of water and nutrients, and through sufficient elimination of yield-limiting factors such as pests, diseases and weeds (Morita *et al.*, 2007)**.** This large yield gap could be attributed to drought, pests and diseases, as well as poor agronomic practices. However, significant advances have been made to adapt green gram to drought through the development of early maturity varieties (Karimi *et al.*, 2019), and closely coupled with consumer-preferred traits such as seed colour and taste (Amjad 2003). Nonetheless, significant yield losses continue to accrue from field pests, particularly pod borers, *Maruca testutalis* (G.), whiteflies, *Bemisia tabaci* (G.) and aphids, *Aphis gossypii,* (G.) (Machocho *et al.*, 2012).

In Kenya, and despite limited data, yield loss in green gram due to field pests could range from 50-90% depending on type of pest and pressure of infestation (Kilimo Trust, 2017). In India, about 40% yield loss is attributed field pests (Prabhaker *et al.*, 2005). These pests cause chewing, piercing and sucking damage on leaves, flowers and young pods (Panneerselvam and Lakshmanan, 2009). The adult pod borer lays eggs on flowers or immature pods while young caterpillars bore into the pod (Ganapathy and Durairaj 2000). They feed from inside the pod and reach a length of 12 -17 mm before making exit holes (Banu *et al.*, 2007). Infested crops wilt and stunt, and the damaged tissues form entry points by secondary pathogens (Bayoumy *et al.*, 2017). Aphids and whiteflies have piercing and sucking mouth parts whose damage leads to deformation, discoloration, stunting and the formation of black sooty mold due to production of honeydew, as well as the transmission of viral diseases (Morita *et al.*, 2007).

Several sources of pest escape, avoidance and resistance to insects have been identified in grain legumes, often controlled by crop developmental rate, morphology and biochemical traits (Hasanuzzaman *et al.*, 2016, Fekri *et al.*, 2013). However, Kenyan green gram varieties have rarely been characterized for these traits. Early maturity varieties escape pest attack by maturing before the pest population multiplies (Halder and Srinivasan, 2011). Crop morphology and biochemical traits significantly alter the pest habitat and behavior (Gomez *et al.*, 2008). Dense crop canopies offer excellent habitat for pests compared with more open structure (Bach, 1980). On the other hand, morphological traits such as leaf pubescence and pod wall thickness modify pest behavior (Girija *et al.*, 2008). Leaf hairs impair movement and feeding of aphids and the larvae of pod borers, while thick pod walls resist mechanical penetration by insects (Sakala *et al.*, 2000).

Owingto climate change and the consequent increase in pest epidemics, new green gram varieties in Kenya such as Karembo, Biashara and Ndengu-Tosha were developed under high insect pressure compared with older counterparts like KS20 and N26. In this regard, the newer varieties could have inadvertently acquired resistance through selection for yield. Thus, the identification of sources of resistance in green gram varieties could open opportunities for the deployment of insect tolerant varieties in Kenya. Studies on host plant tolerance to insect pests in legume crops are restricted to few historically important crops like common bean, *Phaseolus vulgaris* (L.) and pigeon pea, *Cajanus cajan* (L.). The present study examines two old and three new varieties of green gram to identify traits that influence varietal resistance to infestation by pod borers, aphids and whiteflies. The study hypothesized that selection for drought tolerance and yield in Kenyan green gram varieties concomitantly improved resistance to pest infestation, albeit unintended.

## 3.3 Materials and methods

### 3.3.1 Experimental sites

Field experiments were conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) station in Katumani, and in a farmer's field in Katangi, both in Machakos County. This involved two seasons in Katumani during 2020 short rains and 2021 long rains seasons, and one season in Katangi in the course of 2020 short rains. KALRO Katumani is located 1 $^{o}$34′58″S, 37$^{o}$14′43″E and 1600 m elevation. The mean maximum and minimum temperature in Katumani is 25$^{o}$C and 14$^{o}$C, respectively. Soils of this site are well drained dark red to clay with pH 7.0. The farmers' field in Katangi is located 1°40′93″S, 37°68′92″E and 1051 m above sea level. Katangi is hotter than Katumani with mean maximum temperature of 35 °C and minimum 17°C. Soils of Katangi are well drained red brown to clay soils with pH 6.5. Rainfall in both sites has a bimodal distribution pattern, with a long rains season from March to June and a short season from October to December. Long term data show the two sites receive 382 mm during the long rains season, and 274 in the short season.

### 3.3.2 Treatments and experiment design

Treatments comprised five green gram varieties that have contrasting growth rate, morphology and yield attributes. The varieties were two old releases (KS20 and N26) and three new selections which consisted of Biashara, Karembo and Ndengu-Tosha (Tosha). Varieties KS20 and N26 were released in 1990s while Karembo and Biashara were released in 2017, and Ndengu-Tosha is in the final stages of release to the market. Treatments were laid out in a randomized complete block design and replicated in three blocks. To account for spatial variation in the experimental fields, the five green gram varieties were randomly allocated within each of the three blocks of the experiment.

### 3.3.3 Experiment management

In each season, land was tilled prior to onset of rains with a disc plough and harrowed to fine tilth. Crops of green gram were sown at the onset of rains at a spacing of 50cm between rows and 10cm from plant to plant. Plots measured 5m by 5m with 1m alleys between them, and 1.5m between replications. When the crops emerged, cutworms and bean fly were controlled with a single dose of Thunder with active ingredient imidacloprid, and manufactured by Bayer Crop Science AG, Germany, and applied as 10mL/10L water. The pre-harvest interval of imidacloprid is 14 days, and data collection started from 40 days after emergence, hence the chemical did not impact crop infestation by pod borers, whiteflies and aphids. Ridomil with mancozeb as active ingredient, and manufactured by Syngenta Limited in India was applied at 50g/20L water to control bacterial and fungal diseases. A foliar fertilizer of nitrogen, phosphorus and potassium (NPK) and trace elements was applied at 50% branching. Plots were kept weed free by hand weeding.

### 3.3.4 Data collection

Weather data during the growing season was obtained from Kenya Meteorological Department's weather stations near the experiment sites, and included daily rainfall, as well as daily maximum and minimum temperate (https://meteo.go.ke/). Crop phenology was scored periodically but with emphasis on days to 50% branching, flowering and physiological maturity. Crop growth rates varied among the varieties, thus phenological stage was recorded when 50% of plant population in each plot reached the respective growth stage.

Five plants per plot were randomly selected for data collection, and sampling was done early in the morning when the temperature was coolest, and before the pests become active. Pod borer, aphid and whitefly infestation was scored at vegetative, 50% flowering and 50% podding stages. Pod borers and whiteflies were sampled by counting pest numbers on the lower, middle and upper section of the plant canopy, and means computed. Aphid numbers were scored with the use of a 1-5 scale, where; 0 denoted absence of the pest, 1 meant a few scattered individuals, 2 designateda few isolated colonies, 3 represented several isolated colonies, 4 was large isolated colonies, and5 signified large continuous colonies (Mkindi et al. 2017).

Crop morphological traits such as leaf area, leaf hair density and pod wall thickness were measured from 10 randomly selected plants at vegetative, flowering and podding stages. Leaf length and width were measured using a ruler and leaf area was computed and corrected with the use of coefficient 1.46 at vegetative and 1.59 at flowering stage. Leaf hair density was determined per $cm^2$ on the abaxial leaf surface by counting leaf hairs under a dissecting microscope.

At 50% flowering, ten plants were randomly sampled per plot, and nine fully developed leaves removed per plant for moisture determination. Three leaf samples were collected from upper, middle and lower portions of the plant, and bulked for fresh weight determination per plot. Leaves were dried in an oven at 60°C until no further loss in mass, and dry weight determined with a weighing balance. Leaf moisture content (%) was calculated as the ratio between the difference in wet and dry weight, and dry weight.

At physiological maturity, thickness of the pod wall was measured by the use of a vernier calipers in ten randomly selected pods per plot. Collection of seed yield was done differently among the five green gram varieties. For KS20 and Karembo, harvesting was done when pods turned brown while N26, Biashara and Ndengu-Tosha (Tosha) yield was collected when pods turned black. Ten plants were randomly sampled per plot for the determination of number of pods per plant and seeds per pod. Entire plots were harvested but with the exception of guard rows, and seed yield expressed in t/ha.

### 3.4 Data analysis

Data were subjected to analysis of variance (ANOVA) to assess the experimental sources of variation using GenStat 15$^{th}$ Edition. A two-way ANOVA routine was used, with replicate (block) and variety as factors, while variables consisted of the collected measurements. Prior to analysis, data was tested for normality and conformed to requirements of ANOVA. Residuals were checked for normal distribution, and no transformations were required. Treatment means were compared and separated using Fisher's least significant difference (LSD) at 5% probability level. Relationships between crop traits and pest numbers were explored by simple linear regression analysis. Linear regression slopes were tested for significant differences from zero by Sigma Plot version 10.

## 3.5 Results

### 3.5.1 Weather data and crop phenology

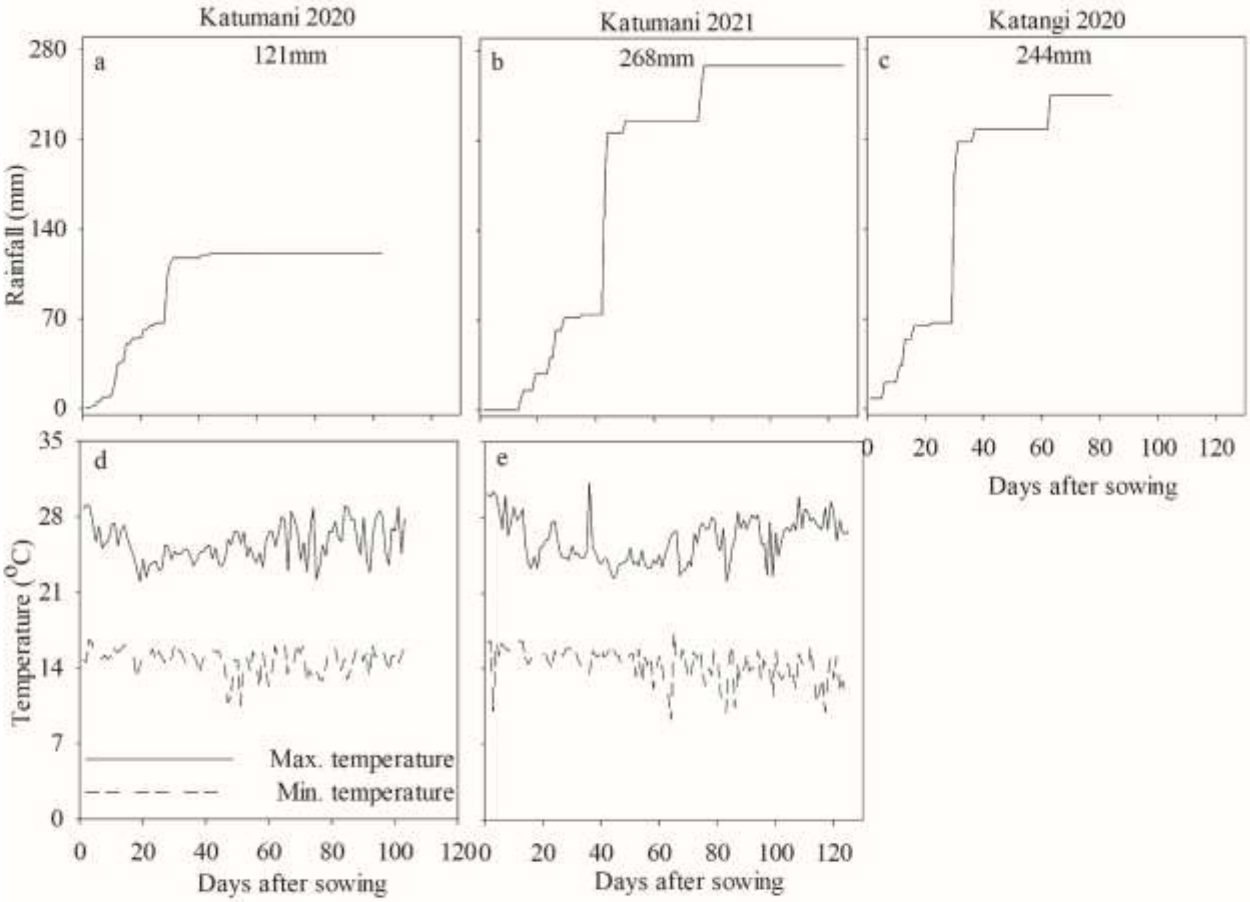


Figure 3.1. Growing conditions for green gram including cumulative rainfall (a, b, c) and estimated daily maximum and minimum temperatures (d, e) in Katumani 2020 short rains, Katumani 2021 long rains and Katangi 2020 short rains

The five green gram varieties showed significant differences ($P<0.05$) in phenology (Table 3.1). Across the three environments, variety KS20 matured earlier than the rest of the varieties while N26 was late. Varieties Biashara, Karembo and Ndengu-Tosha were intermediate in maturity. On average in the cooler Katumani site, KS20 attained 50% branching in 35 days, 50% flowering in 49 days and matured in 89 days while in Katangi, the same variety took 28 days, 42 days and 72 days to branch, flower and mature, respectively. On the other hand, the late maturing N26 attained 50% branching in 44 days and flowered in 61 days in both Katumani and Katangi but matured in 83 days in Katangi, and took 114 days in Katumani. In the cooler environments of Katumani, the intermediate varieties (Karembo, Biashara and Ndengu-Tosha) branched in 42 days, flowered in

56 days and matured in 88 days while in Katangi the varieties took 39, 51 and 74 days to reach 50% branching, flowering and physiological maturity, respectively.

Table 3.1. Mean days to 50% branching, flowering and physiological maturity of five green gram varieties grown in Katumani and Katangi during 2020 short rains and 2021 long rains

| Variety | Katumani 2020 | | | Katangi 2020 | | | Katumani 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Branch | Flower | Maturity | Branch | Flower | Maturity | Branch | Flower | Maturity |
| N26 | 46a | 61a | 103a | 42a | 61a | 83a | 51a | 69a | 124a |
| KS20 | 31d | 46d | 82d | 28d | 42d | 72c | 38d | 52d | 96d |
| Karembo | 41c | 55c | 92b | 39b | 49b | 76b | 46b | 62b | 106c |
| Biashara | 42c | 55c | 86c | 38b | 50b | 72c | 51a | 64b | 111b |
| Tosha | 44b | 57b | 86c | 41c | 55c | 73bc | 41c | 60c | 96d |
| P Value | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| LSD | 1.90 | 1.48 | 1.06 | 1.80 | 2.20 | 1.70 | 1.30 | 1.10 | 1.50 |
| % CV | 2.5 | 1.4 | 0.6 | 2.6 | 2.2 | 1.2 | 1.5 | 1.0 | 0.7 |

Means followed by the letter within a column are not significantly different, at $P \leq 0.05$.

### 3.5.2 Leaf area

Leaf area varied significantly ($P<0.05$) among the varieties (Table 3.2). On average, variety N26 had larger leaf area compared with rest of the varieties in all environments. Variety KS20 had the smallest leaf area while that of Biashara, Karembo and Ndengu-Tosha was intermediate. However, a large variation in leaf area was recorded across the three environments, usually with higher dimensions in wetter seasons.

### 3.5.3 Leaf hair density

Table 3.3 presents leaf hair density per $cm^2$ at vegetative and flowering stages among the collection of green gram varieties. Variety KS20 had significantly higher number of leaf hairs compared with the rest of varieties while N26 had the least hairs. The three new varieties had intermediate leaf hair density compared with their older counterparts. However, Karembo consistently recorded a higher number of leaf hairs among the new releases.

3.5.4 Leaf moisture content and pod-husk thickness

The varieties showed significant differences in leaf moisture content in Katumani and Katangi during the 2020 short rains except in Katumani in 2021 long rains. Variety N26 had significantly higher leaf moisture content while KS20 had the lowest. Varieties Biashara, Karembo and Ndengu-Tosha were in the intermediary (Table 3.4).

Differences in pod wall thickness were measured during the wetter 2020 season but without differences in the drier 2021 season. Variety N26 had thicker pod walls of 10 -13 mm compared with the rest of varieties. However, Karembo recorded thicker pod walls among the four varieties with thinner husks compared (Table 3.4).

Table 3.2. Mean leaf area ($cm^2$) of five green gram varieties at vegetative and flowering stage in Katumani and Katangi during 2020 short rains and 2021 long rains

| | Katumani 2020 | | Katangi 2020 | | Katumani 2021 | |
|---|---|---|---|---|---|---|
| Variety | Vegetative | Flowering | Vegetative | Flowering | Vegetative | Flowering |
| N26 | 51.6c | 61.1c | 63.8c | 94.3d | 117.3c | 78.8a |
| KS20 | 38.1b | 48.9b | 32.7a | 47.7a | 96.3b | 71.7b |
| Karembo | 30.1a | 41.6b | 39.1b | 53.9b | 94.6b | 67.2a |
| Biashara | 34ab | 37.2a | 58c | 68.5c | 76a | 73.4a |
| Tosha | 37.2b | 46.6a | 40.5b | 54.1b | 99.4b | 68.4a |
| P Value | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.153 |
| LSD | 5.636 | 4.4 | 5.817 | 3.021 | 13.07 | 10.03 |
| % CV | 7.8 | 5 | 6.6 | 2.5 | 7.2 | 7.4 |

Means followed by the letter within a column are not significantly different, at P≤0.05.

Table 3.3. Mean leaf hair density per cm2 of five green gram varieties during vegetative and floweringgrowth stage of the crop in Katumani and Katangi during 2020 short rains and 2021 long rains

| | Katumani 2020 | | Katangi 2020 | | Katumani 2021 | |
|---|---|---|---|---|---|---|
| Variety | Vegetative | Flowering | Vegetative | Flowering | Vegetative | Flowering |
| N26 | 47.1a | 47.1a | 38.5a | 37.1a | 47.8a | 61.8a |
| KS20 | 100.3e | 101.3e | 98.6d | 99.6e | 71.6d | 92.9b |
| Karembo | 70.3d | 72d | 59.9c | 55.6c | 50.4ab | 55.7a |
| Biashara | 53.2b | 57.3b | 42.8b | 45.8b | 57.1c | 61.5a |
| Tosha | 66.2c | 66c | 40.8ab | 67.3d | 55.1bc | 58.3a |
| P Value | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| LSD | 2.936 | 2.542 | 2.974 | 3.513 | 5.994 | 6.417 |
| % CV | 2.3 | 2 | 2.8 | 3.1 | 5.6 | 5.2 |

Means followed by the letter within a column are not significantly different, at P≤0.05.

Table 3.4. Mean leaf moisture content and husk thickness in five green gram varieties in Katumani andKatangi during 2020 short rains and 2021 long rains

| Variety | Leaf moisture content (%) | | | Pod husk thickness (mm) | | |
|---|---|---|---|---|---|---|
| | Katumani 2020 | Katangi 2020 | Katumani 2021 | Katumani 2020 | Katangi 2020 | Katumani 2021 |
| N26 | 74.8a | 78.1a | 81.8a | 8.6a | 9.7a | 0.6a |
| KS20 | 48.2e | 37.8e | 80.2a | 10.2b | 13.0b | 0.7a |
| Karembo | 71.2d | 57.8d | 79.8a | 8.2a | 10.9a | 0.6a |
| Biashara | 55.3b | 44.3b | 78.9a | 7.2a | 11.7a | 0.7a |
| Tosha | 66.1c | 54.0c | 78.8a | 7.4a | 10.1a | 0.7a |
| P Value | 0.001 | 0.001 | 0.911 | 0.011 | 0.015 | 0.312 |
| LSD | 2.20 | 1.92 | 8.06 | 1.51 | 1.72 | 0.12 |
| % CV | 1.7 | 1.7 | 5.4 | 9.6 | 8.3 | 9.8 |

Means followed by the letter within a column are not significantly different, at $P \leq 0.05$

### 3.5.5 Pest infestation on green gram varieties

#### 3.5.5.1 Pod borer infestation on varieties

Table 5 shows the number of pod borers per plant during vegetative, flowering and podding stages of green gram. Variety significantly modulated pod borer infestation where N26 recorded the highest population and the least was in KS20. On average, N26 had a mean of 3.0 while variety KS20 showed a mean of 0.4 of pod borer infestation across the sites. The new varieties presented intermediary infestation levels but Karembo had a significant higher population of 2.1 pod borers per plant.

#### 3.5.5.2 Whitefly infestation on varieties

Significant differences were observed on whitefly infestation between the five varieties in Katumani 2020 and Katangi 2020 in all the crop growth stages except in Katumani 2021 where a significant difference was observed only in the vegetative stage (Table 3.6). On average, variety N26 showed the highest means of whitefly infestation of 2.0 while variety KS20 showed the lowest means of 0.6 across the three sites. Similar means were observed in varieties Karembo, Biashara and Ndengu-Tosha with Ndengu-Tosha having the least mean of 0.7 among the three varieties.

#### 3.5.5.3 Aphid infestation on varieties

Significant differences were observed on aphid infestation on the five varieties across the three sites. Variety N26 showed highest aphid's infestation while variety KS20 showed the lowest aphid's infestation, where else varieties Biashara, Karembo and Ndengu -Tosha showed intermediate aphid's infestation across the three sites (Table 3.7). On average variety N26 showed a mean of 2.1 while variety KS20 showed 0.6 of aphid's infestation. Across the two Katumani sites, varieties Karembo, Biashara and Ndengu-Tosha showed an average means 0.75, 1.4 and 1.2 respectively while in Katangi 2020 showed 0.8, 1.4 and 0.8 means of aphid's infestation.

Table 3.5. Mean number of pod borers at vegetative, flowering and podding stages in five green gram varieties grown in Katumani and Katangi during 2020 short rains and 2021 long rains

| Variety | Katumani 2020 | | | Katangi 2020 | | | Katumani 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Veg | Flowe | Podding | Vegetative | Flowering | Podding | Vegetative | Flowering | Podding |
| N26 | 2.5c | 2.5e | 3.5b | 2.1d | 2.5c | 6.1c | 2.0d | 2.9c | 2.9d |
| KS20 | 0.2a | 0.1a | 0.2a | 0.1a | 0.2a | 1.6b | 0.1a | 0.2a | 0.7ab |
| Karembo | 1.7b | 1.6d | 0.6a | 1.9b | 1.8b | 5.6a | 1.2c | 2.0b | 2.1c |
| Biashara | 0.3a | 0.7b | 0.5a | 0.9c | 0.3b | 3.4b | 0.3b | 0.4a | 1.3b |
| Tosha | 0.4a | 1.1c | 0.5a | 1.2b | 0.1a | 3.7b | 0.3ab | 0.3a | 0.4a |
| P Value | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 |
| LSD | 0.58 | 0.32 | 0.59 | 0.21 | 0.26 | 1.26 | 0.21 | 0.31 | 0.65 |
| % CV | 30.3 | 14.3 | 29.9 | 8.9 | 14.5 | 16.5 | 14.3 | 14.5 | 23.6 |

Means followed by the letter within a column are not significantly different

Table 3.6. Mean number of whiteflies on five green gram varieties during vegetative, flowering andpodding growth stage in Katumani and Katangi during 2020 short rains and 2021 long rains

| Variety | Katumani 2020 | | | Katangi 2020 | | | Katumani 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Vegetative | Flowering | Podding | Vegetative | Flowering | Podding | Vegetative | Flowering | Podding |
| N26 | 4.2b | 2.4b | 1.4b | 2.9d | 3.0c | 1.8c | 1.2c | 0.7 | 0.5 |
| KS20 | 1.5a | 0.7a | 0.6a | 0.2a | 1.2a | 0.5b | 0.4ab | 0.4 | 0.3 |
| Karembo | 1.9a | 2.3b | 0.6a | 1.3c | 1.1b | 1.1c | 0.4ab | 0.3 | 0.4 |
| Biashara | 1.6a | 0.7a | 1.0ab | 1.8b | 1.7a | 1.4b | 0.7b | 0.6 | 0.4 |
| Tosha | 1.9a | 1.2ab | 1.1ab | 0.3b | 2.3a | 0.4a | 0.3c | 0.6 | 0.4 |
| P Value | 0.001 | 0.003 | 0.038 | 0.001 | 0.001 | 0.001 | 0.001 | 0.533 | 0.815 |
| LSD | 0.70 | 1.26 | 0.54 | 0.20 | 0.43 | 0.49 | 0.33 | 0.57 | 0.30 |
| % CV | 16.8 | 46 | 31.6 | 8.5 | 12.9 | 26.4 | 30.2 | 56.7 | 43.3 |

Means followed by the letter within a column are not significantly different

Table 3.7. Mean number of aphids on five green gram varieties during vegetative and flowering growthstage in Katumani and Katangi during 2020 short rains and 2021 long rains

| Variety | Katumani 2020 | | | Katangi 2020 | | | Katumani 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| | Vegetative | Flowering | Podding | Vegetative | Flowering | Podding | Vegetative | Flowering | Podding |
| N26 | 2.0e | 2.6d | 2.2c | 0.6d | 2.4d | 1.3c | 2.0d | 3.7c | 2.2c |
| KS20 | 0.2a | 0.5a | 0.7a | 0.3a | 0.4a | 0.8a | 0.5a | 0.9a | 0.7a |
| Karembo | 0.5b | 1.4c | 0.7a | 0.8b | 1.4a | 0.3b | 0.7ab | 2.0b | 1.0ab |
| Biashara | 1.1d | 1.3c | 0.9ab | 1.6c | 1.9b | 0.7bc | 1.4c | 2.0b | 1.5b |
| Tosha | 0.9c | 0.9b | 1.3b | 1.1a | 0.4c | 1.0a | 1.0b | 1.7b | 1.4b |
| P Value | 0.001 | 0.001 | 0.001 | 0.001 | 0.001 | 0.003 | 0.001 | 0.001 | 0.003 |
| LSD | 0.2 | 0.35 | 0.42 | 0.39 | 0.51 | 0.38 | 0.27 | 0.35 | 0.59 |
| % CV | 12.6 | 14.3 | 18.8 | 16 | 20.5 | 25.2 | 12.9 | 9.1 | 23.4 |

Means followed by the letter within a column are not significantly different

### 3.5.6 Yield components

#### 3.5.6.1 Number of pods per plant seeds per pod

Varieties showed significant differences between numbers of seeds per pod and number of pods per plant in the three sites (Table 3.8). Variety N26 showed the highest number of seeds per pod and number of pods per plant with average means of 22.2 and 62.5 respectively while variety KS20 had the lowest number of seeds and number of pods with average means of 8.8 and 49.6 while Biashara, Karembo and Ndengu-tosha showed similar numbers of seeds and pods.

#### 3.5.6.2 Seed yield and 100 seed weight

In Katumani, both 2020/2021 N26 showed the highest yield of 2.13 t/ha and 1.5 t/ha respectively with KS20 having the lowest yield of 0.57 t/ha and 0.27t/ha while in Katangi 2020 Bashara had thehighest yield of 1.48 t/ha and variety Karembo showed the lowest yield of 0.73 t/ha.

Seed weight showed a significant difference only in Katangi 2020 while in yield there was a significant difference among all the three sites (Table 3.9). Under seed weight, N26 showed highest seed weight of 7.5g while KS20 had the lowest seed weight of 5.5gand the other varieties showed intermediate seed weight with Biashara having the highest among the three.

Table 3.8. Mean number of seeds per pod and pod per plant in five green varieties inKatumani and Katangi during 2020 short rains and 2021 long rains

| Variety | Seeds per pod | | | Pods per plant | | |
|---|---|---|---|---|---|---|
| | Katumani 2020 | Katangi 2020 | Katumani 2021 | Katumani 2020 | Katangi 2020 | Katumani 2021 |
| N26 | 31.3d | 24.3c | 11.1c | 91.0a | 85.7c | 10.9b |
| KS20 | 10.7a | 12.5a | 3.2c | 88.7e | 55.8a | 4.4a |
| Karembo | 18.1c | 16.9b | 6.5ab | 89.0d | 72.1b | 8.2a |
| Biashara | 13.1ab | 19.0b | 5.4a | 85.3b | 78.0b | 5.9a |
| Tosha | 14.8bc | 17.8b | 7.0b | 89.7c | 74.0b | 5.0a |
| P Value | 0.001 | 0.001 | 0.001 | 0.018 | 0.048 | 0.008 |
| LSD | 3.78 | 3.80 | 1.13 | 2.90 | 15.90 | 3.30 |
| % CV | 11.4 | 11.2 | 7.5 | 1.7 | 11.7 | 28.9 |

Means followed by the letter within a column are not significantly different

Table 3.9. 100 seed weight (g) and mean grain yield (t/ha) of five green gram varieties in Katumani andKatangi during 2020 short rains and 2021 long rains

| Variety | 100 seed weight (g) | | | Grain yield (t/ha) | | |
|---|---|---|---|---|---|---|
| | Katumani 2020 | Katangi 2020 | Katumani 2021 | Katumani 2020 | Katangi 2020 | Katumani 2021 |
| N26 | 6.9 | 7.5c | 6.2 | 2.13d | 0.81c | 1.5c |
| KS20 | 6.6 | 5.5a | 5.9 | 0.57a | 0.95b | 0.27a |
| Karembo | 6.8 | 6.3b | 6.5 | 0.97bc | 0.73ac | 0.44b |
| Biashara | 6.4 | 6.5b | 6.9 | 0.70d | 1.48d | 0.29a |
| Tosha | 6.7 | 6.3b | 6.4 | 1.08b | 0.82c | 0.45b |
| P Value | 0.444 | 0.002 | 0.274 | 0.004 | 0.001 | 0.001 |
| LSD | 0.19 | 0.16 | 0.97 | 0.73 | 0.98 | 0.14 |
| % CV | 30.2 | 22.4 | 8.1 | 5.6 | 20.3 | 41.4 |

Means followed by the letter within a column are not significantly different

### 3.5.7 Relationship between crop phenology, crop morphological traits and pest infestation

#### 3.5.7.1 Relationship between crop phenology and pest infestation

Positive associations were measured between crop phenology and pest infestation (Figure 3.2 and 3.3). Late maturity varieties showed higher number of pod borers, aphids and whiteflies compared with their early maturity counterparts, at both branching and flowering stages.

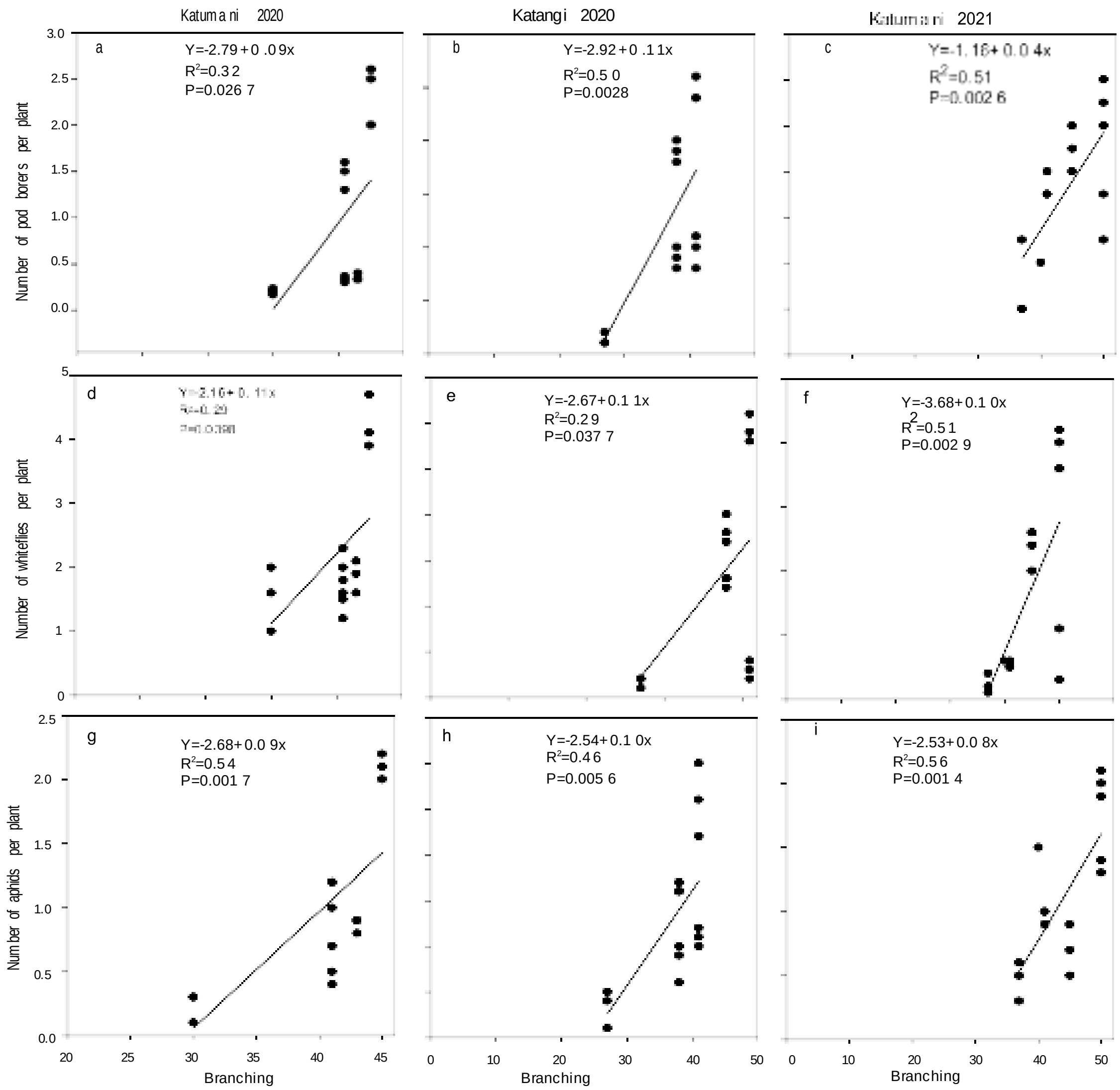

Figure 3.2. Relationship between days to branching and pod borers (a, b, c), whiteflies (d, e, f) and aphids (g, h, i) during vegetative stage in five green gram varieties grown in Katumani 2020/2021 and Katangi 2020 short and long rains.

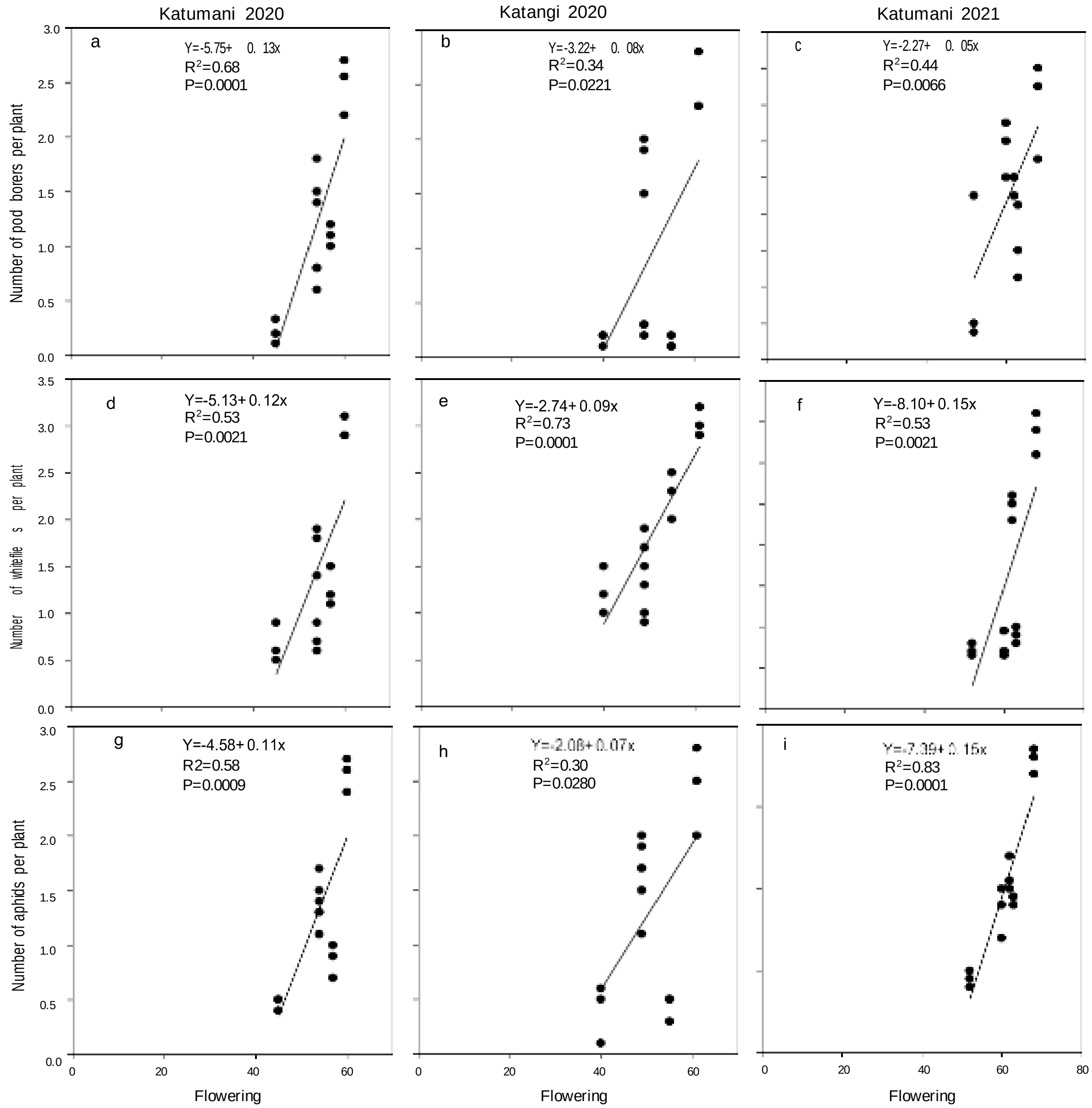


Figure 3.3. Relationship between days to crop flowering and pod borers (a, b, c), whiteflies (d, e, f) and aphids (g, h, i) during vegetative stage in five green gram varieties grown in Katumani 2020/2021 and Katangi 2020 short and long rains

3.5.7.2 Relationship between leaf area and pest infestation at vegetative stage

Figure 3.4 presents associations between leaf area and pest infestation at the vegetative. Number of pod borers per plant positively ($R^2 = 0.33$) but weakly correlated with leaf area in the three cropping environments (a, b, c). Similarly, a weak relationship was observed between whitefly numbers and leaf area with average $R^2$ of 0.5 (d, e, f). However, a strong relationship was measured between leaf area and whitefly infestation with an average R of 0.65 (g, h, i) across the three sites.

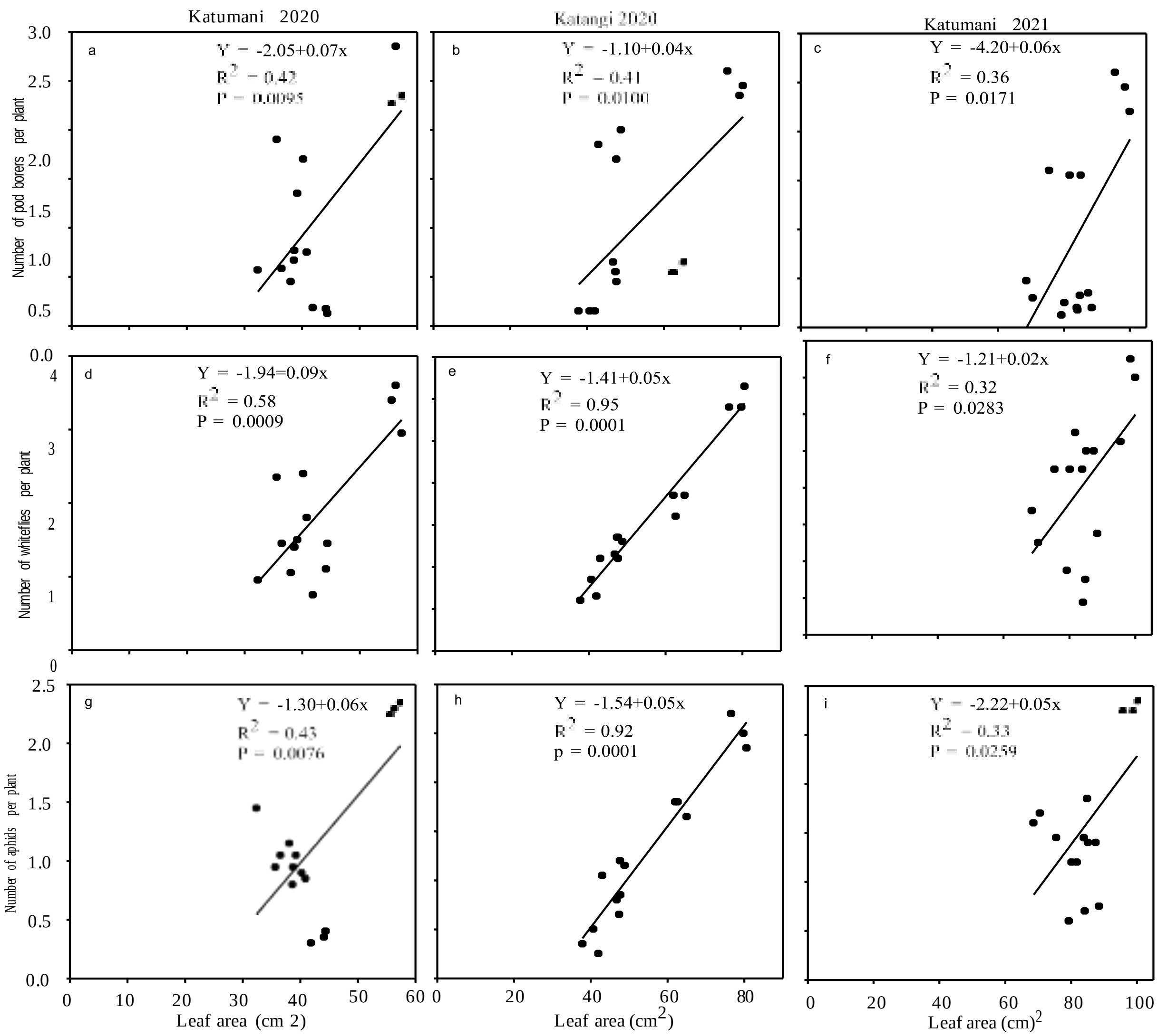


Figure 3.4. Relationship between leaf area (cm) and number pod borers (a, b, c), whiteflies (d, e, f) and aphids (g, h, i) during vegetative stage in five green gram varieties grown in Katumani 2020/2021 and Katangi 2020 short and long rains

3.5.7.3 Relationship between leaf area and pest infestation at flowering stage

Under flowering stage, leaf area showed significant difference and positive correlation however, the association between leaf area and number of pests was weak between the three pests, pod borers showed an average $R^2$ of 0.29 (a, b, c), whiteflies 0.44 (d, e, f) and aphids 0.42 (5 g, h, i) respectively.

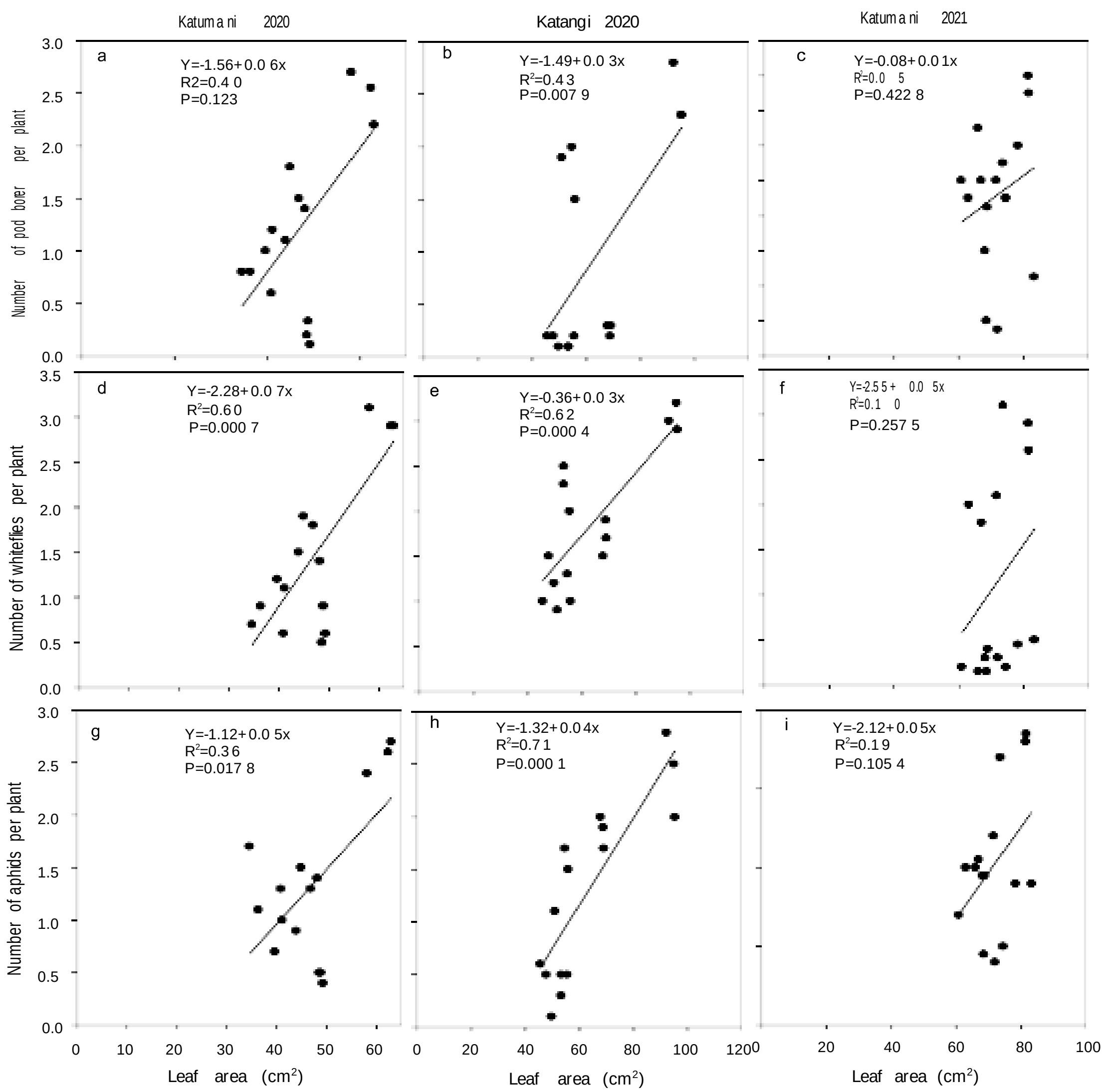


Figure 3.5. Relationship between leaf area (cm) and number pod borers (a, b, c), whiteflies (d, e, f) and aphids (g, h, i) during flowering stage in five green gram varieties grown in Katumani 2020/2021 and Katangi 2020 short and long rains

3.5.7.4 Relationship between leaf hair density and pest infestation at vegetative stage

Figure 3.6 shows association between leaf hair density and pest population. Leaf hair density negative (P>0.05) impacted pod borer, whitefly and aphid population. Leaf hair density showed a significant difference. There was a negative correlation and strong association between number of pests and leaf hair density in pod borers and aphids with an average $R^2$ of 0.61 and 0.59 and p >0.05 respectively while number of whiteflies showed a weaker association to leaf area with a $R^2$ of 0.40 across the sites.

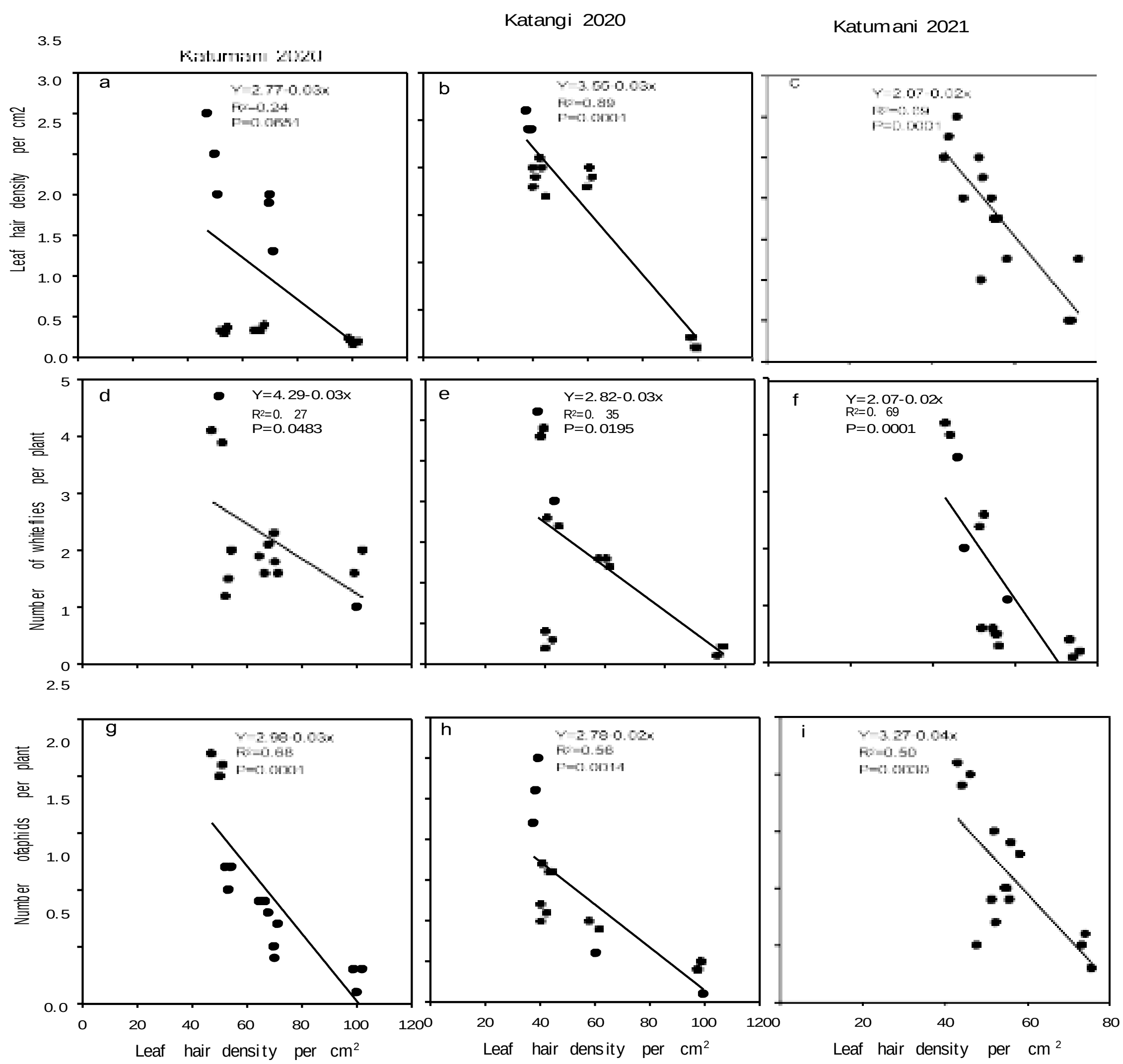


Figure 3.6. Relationship between leaf hair density (cm²) and number of pod borers (a, b, c), whiteflies (d, e, f) and aphids (g, h, i) during vegetative stage in five green gram varieties grown in Katumani 2020/2021 and Katangi 2020 short and long rains

3.5.7.5 Relationship between leaf hair density and pest infestation at flowering stage

There was significant difference and negative correlation between leaf hair density and pest population during flowering stage of the crop, p<0.05 with pod borers having 0.57,0.76,0.51, whiteflies 0.39,0.28,0.05 and aphids 0.66, 0.73 ,0.76 in Katumani 2020/2021 and Katangi 2020 accordingly.

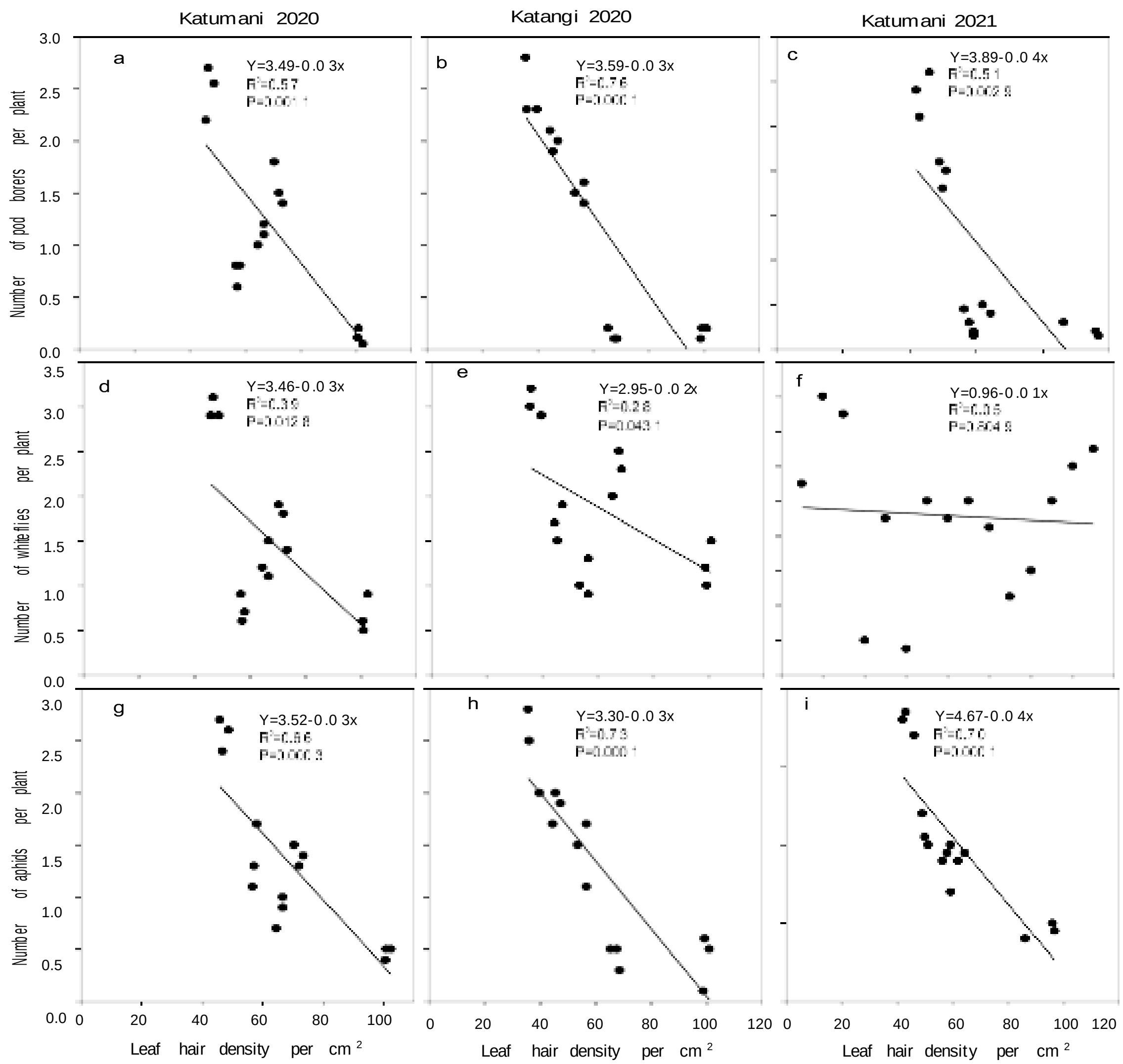


Figure 3.7. Relationship between leaf hair density (cm²) and number of pod borers (a, b, c), whiteflies (d, e, f) and aphids (g, h, i) during flowering stage in five green gram varieties grown in Katumani 2020/2021 and Katangi 2020 short and long rain

3.5.7.6 Relationship between pod wall thickness and pod borer infestation

Husk thickness showed a significant difference, where the $p<0.05$, and negative correlation to pod borers population within the three sites Among the sites, the correlations showed $R^2$=0.54, 0.62, 0.57 in Katumani 2020, Katangi 2020 and Katumani 2021. This shows strong association between husk thickness and pod borer numbers.

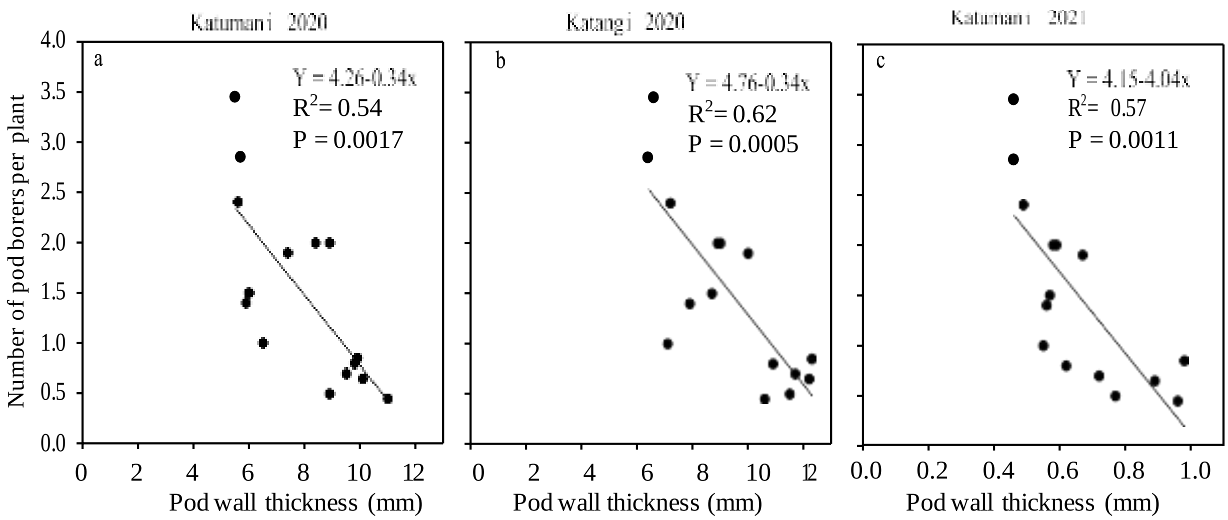


Figure 3.8. Relationship between pod wall thickness (mm) and number of pod borers (a, b, c) in five green gram varieties grown in Katumani and Katangi 2020 short and long rains

3.5.7.7 Relationship between leaf moisture content and pest infestation

Leaf moisture showed a significant difference to number of whiteflies and aphids. Both pests showed a strong association to leaf moisture content with an average R² of 0.78 and 0.64 respectively with whiteflies have the strongest association of 0.78. (Figure 3.9).

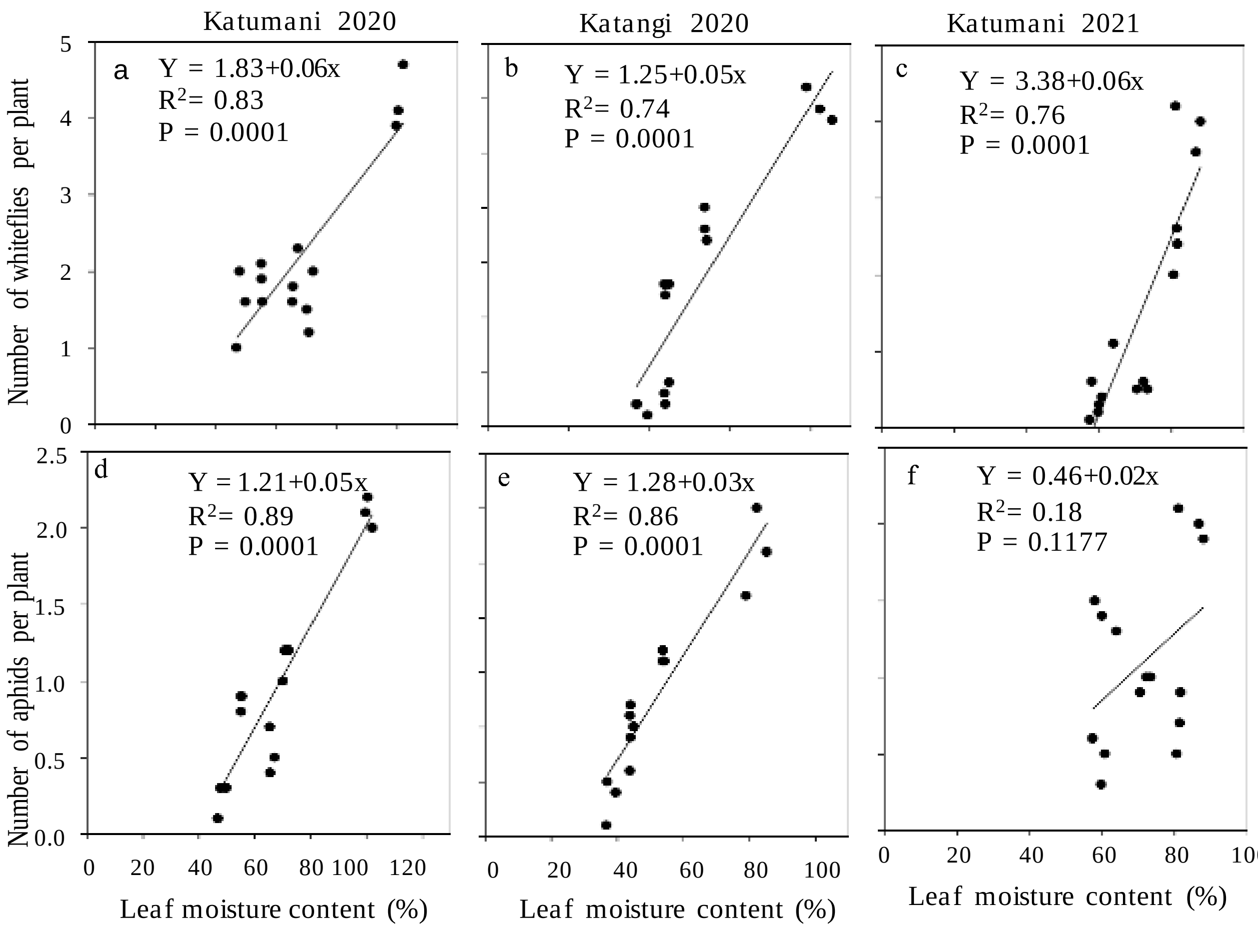


Figure 3.9. Relationship between leaf moisture content (%) and number of whiteflies (a, b, c) and aphids (d, e, f) in five green gram varieties grown in Katumani and Katangi 2020 short and long rains

## 3.6 Discussion

Breeding of green gram in Kenya has significantly improved adaptation to moisture stress but with limited attention to field pests, which continue to cause marked yield losses. The present study provides knowledge into some of the mechanisms conferring the tolerance of green gram to pod borer, aphid and whitefly infestation in semi-arid regions of Kenya. Among the selection of varieties, earliness contributed to the escape of pest attack while the crop morphological traits modulated infestation rate. There were no particular associations between traits for tolerance to pest infestation and the year of variety release (old versus new varieties). Thus, however unintended, breeding has not selected for particular traits of tolerance to pest infestation in green gram.

### 3.6.1 Green gram phenology and pest infestation

Pod borers, whiteflies and aphids' infestation on the five green gram varieties differed significantly with the pests showing high abundance in N26 variety and less abundance in variety KS20**.** The differences in pest numbers and population can be associated with genetic variations among the varieties, crop morphological and physiological factors as well as environmental factors and this conforms closely to (Amjad *et al.,* 2009) whose results showed variations in the number of whiteflies, thrips and aphids on different cotton varieties with more preference on one particular variety. Pest infestation variations among the varieties can also be contributed to biochemical factors, leaf chemical composition and green leaf volatiles produced by the different plant species as well as environmental factors (Hasanuzzaman *et al.*, 2016).

Crop phenology showed positive correlations to pest infestation, these present results are similar to (Warfield, 1996) where the results showed that different varieties have different susceptibility and resistance levels to pest population. Varieties differently affects host selection, pest survival, colonization success and daily reproduction which is contributed by the host biochemical compositions which are unfavorable to the pest, type of damage by the pest, feeding guild and duration (Quandahor *et al.*, 2019). Biochemical compositions like phenols have a direct toxicity to the pest hence deterring it from feeding and growth (Mohan *et al.*, 1987).

Data collected showed positive correlation between crop phenology during branching/vegetative and flowering to pest numbers, this means that as the crop grew more pest numbers were observed. However, pod borers showed a weak correlation while whiteflies and aphids number showed a strong positive correlation to crop growth stages, these results concur with (Nadeem *et al.*, 2020) who found out whiteflies and aphids as sucking pests increases as the crop grows and is peak at the branching stage due to increase in leaf area and leaf moisture content. Pod borer numbers fluctuated during branching and flowering until the crop reached at podding when the population was at its highest, the results of current studies are in conformity to (Palomo *et al.*, 2015), who found pod borers population is at peak when the crop begins to form pods.

Significant differences were observed between varieties and yield, numbers of pods per plant and number of seeds per pod across the three sites. Variety N26 showed the highest yield, number of pods and number of seeds per pod while variety KS20 had the lowest yield, number of pods and number of seeds. Biashara, Karembo and Ndengu-tosha showed similar yields, numbers of pods and seeds (Figure 3.3), similarly (Halder *et al.*, 2006) found out that mungbean varieties that had high pest infestation and damage showed highest number of pods and clusters as seen with variety N26.

3.6.2 Modulation of pest infestation by crop morphological traits and yield components

Morphological traits of a plant can affect the pest population through interference with host selection, feeding, ingestion, digestion, mating and oviposition (Quandahor *et al.*, 2019). Leaf area and leaf moisture content showed a positive correlation (Figure 3. 4 and 3.6) while leaf hair density and pod wall thickness showed a negative correlation to pest infestation (Figure 3.5 and 3.7). Positive correlation meant that increase in the crop's morphological trait led to increase in pest numbers while negative correlation showed that increase in morphological trait led to decrease in the number of pests. Pest density increased as the crop grew while per leaf the pest population decreased with crop growth hence injury was more severe at early stages than late stages of the crop whereby the larvae are small and vigorously feeds on the growing leaves especially in pod borers (Yamamura *et al.*, 1999).

Leaf hair showed a significance and negative correlation to the pest population just as seen in (Zia *et al.*, 2011) whereby increase in the leaf hair density led to decrease in the number of pests while decrease in leaf hair density led to increase in the number of pod borers, whiteflies and aphids Leaf hairs are known to interfere with insect oviposition, attachment to the plant during feeding and ingestion (Ihsan-ul-Haq *et al.*, 2003). Leaf hairs are attributed as a source of resistance by the crop to pests' infestation, length of the leaf hairs and gossypol glands are known to mechanically hinders pest movement as it reduces the grip ability of the pest on the crop and longer leaf hairs make the crop more susceptible than shorter leaf hairs to pest attack and when the number of leaf hairs on the crop are less, pest numbers seem to be lower compared to many leaf hairs on the crop. (Rustamani *et al.*, 2014).

Leaf area showed a positive correlation to number of pod borers, whiteflies and aphids which meant that increase in leaf area increased number of pest while decrease in leaf area lead to a decrease in pest population, this is also the case by (Martin *et al.*, 1996) which showed a significantly positive correlation between leaf area to pest populations and concluded that increasein leaf area lead to pest population increase as well hence providing the pest with a large area for movement and feeding of the crop (Bach, 1980). In this study, variety KS20 showed highest leaf hair density with low pest infestation while variety N26 showed lowest leaf hair density with highest pest infestation levels, high leaf hair density leads to severe interfere with insect movement, oviposition, attachment to the plant during feeding and ingestion hence less pest population and vice versa (Ihsan-ul-Haq *et al.*, 2003).

Leaf moisture content showed a strong correlation to whiteflies and aphids' population with $R^2$ of 0.78 and 0.64 with a p of 0.0001 (Figure 5), the results shows that, an increase in leaf moisture content leads to increase in whiteflies and aphids pest population hence a positive correlation between leaf moisture and the pests, the present results were similar to (Khan *et al.*, 2011 ) and (Nahrung *et al.*, 2012),whereby their results showed a positive correlation between leaf moisture content to thrips and pod borers population while ( Zia *et al.*, 2011) results also showed similar results between whitefly and leaf moisture content. However, the present studies are in contradiction to (Gomes *et al.*, 2008) that from who reported that increase in leaf moisture content led to lower pest population because whitefly and aphids, are known to suck the moisture content of the leaf affecting the photosynthetic process of the crop due to formation of honey dew which reduces the chlorophyll content of the crop as well as death of the crop leaving no food for the pest too.

Husk thickness was significant different and showed a positive correlation to pod borers population, the variety that had the highest husk thickness,KS20,showed lowest pod borer infestation and attacks while the varieties that had lowest husk thickness,N26, showed highest pod borer infestation, this present results are similar to (Halder and Srinivasan, 2011) who found out that green gram varieties that had highest pod wall thickness suffered lowest pod damage and less pest infestation as well as (Halder and Srinivasan, 2007). Husk contains lignin and cellulose content which are plant biochemical composition that are toxic to pests and varieties showed tolerance to pod borers attacks hence reducing pod damage acting as barrier to pest attacks. (Girija,2008) and acts as a barrier to pest attack (Warfield, 1996).

Significant differences were observed between varieties and yield, numbers of pods per plant and number of seeds per pod across the three sites. Variety N26 showed the highest yield, number of pods per plant and number of seeds per pod while variety KS20 had the lowest yield, number of pods and number of seeds while Biashara, Karembo and Ndengu-Tosha showed similar yields, numbers of pods and seeds (Figure 2), similarly (Halder *et al.*, 2006) found out that mungbean varieties that had high pest infestation and damage showed highest number of pods and clusters.

### 3.7 Conclusion

Significant varietal differences exist between crop phenology and the morphological traits among the evaluated varieties. Variety that expressed superior agronomic traits such KS20 and Biashara are recommended for adoption by farmers and breeding programmes although N26 performed better in yield. There is need for farmers to be sensitized to adopt the new varieties due to their early maturity and yield performances as seen in Biashara variety. Leaf area and leaf moisture content showed a positive correlation to pest numbers while leaf hair density and pod husk thickness showed a negative correlation to the pest numbers**.** Positive correlation indicated that increase in the measured factors increase the pest numbers, increased leaf area surface provides more space and favors the pest to feed, mate and even protection from predators while more leaf moisture content provides more, especially for sucking pests, for the pest to feed and hide from predators.

# CHAPTER FOUR: DETERMINATION OF THE EFFICACY OF SELECTED CRUDE PLANT EXTRACTS IN THE MANAGEMENT OF POD BORERS, APHIDS AND WHITEFLIES IN GREEN GRAM

## 4.1 Abstract

Continuous use of synthetic pesticides causes serious health and environmental consequences. To reduce these challenges, and lower the cost of production, farmers rely on indigenous knowledge to manage crop pests. Several plant species are known to have insecticidal properties against a range of insect pest. Despite growth on research, there is limited data on pesticidal plants and only a few of them have been commercialized for pest management hence remaining a small but growing component in crop protection. This study aimed at evaluating the efficacy of four plant extracts of diverse species, including neem (*Azadirachta indica*), melia *(Melia volkensii)*, tick berry (*Lantana camara)* and garlic (*Allium sativum)* in the management of green gram, N26 variety, field pests. Respective plant extracts were prepared and applied at 10mL/20L of water at seven days interval and compared to lambda_cyhalothrin which was applied at the rate of 5mL/20L of water as a standard check and untreated control. Crops applied with tick berry and melia plant extracts showed significantly higher number of pod borers, aphids, whiteflies and natural enemies of about 70-80% compared to neem and garlic which showed 40-50% of the pest numbers. Pod damage was highest in melia and tick berry ranging from 70-90% and lowest in neem and garlic with a range of 36-63% accordingly. For yield components, garlic showed highest yields with in terms of pod numbers, seeds per pod and the overall yield of 2.8t/ha while melia showed lowest yields of 2.6t/ha with neem and tick berry having intermediate yield potentials of respectively. The four plant extracts offered an effective control of key pest species, especially neem and garlic extracts, that was comparable in terms of yield harvested to the synthetic pesticide. Significantly, the plant extracts had lower negative impact on the beneficial organisms thus supporting the ecosystem while managing the pests

***Key words*;** Botanicals, pest numbers, pesticide, beneficial organisms

## 4.2 Introduction

Plant extracts have been used for insect control and help obtain sustainable production due to their insecticidal activities against the pests. They have exhibited different insecticidal effects against the pests such as interference with the pest's feeding behavior due to their repellant effect, reduced movement, stomach indigestion, stunted and pest mortality (Elechi and Ekemezie, 2020; Mhazo *et al.*, 2011).

Different plant extracts concentrations have been used and found out that 10% w/v concentrations are very effective to manage pests compared to the other concentrations (Mkindi *et al.*, 2017)**.** According to (Belmain *et al.*, 2012)**,**10% concentration of plant extract requires, one kilogram of the plant extract powder mixed with 10 liters of water at 15 -24$^{o}$C for 24 hours. In order to improve on the pesticide extraction efficiency, soap detergent is added and mixed with the pesticide concentration as a sticker and spraying should be done within a 7 days interval after each application (Tembo *et al.*, 2018). They can be derived from plant parts such as the leaves, flowers, seeds or in bulbs as for garlic where they are prepared into concentrations that can be used f or pests management (Rahman *et al.*, 2016)**.**

Plants used as botanicals have different active ingredients that affect the pest in various ways; some have repellant, ovicidal, antifeedant and toxic effects on the pests (Isman, 2008)**.** Neem contains azadirachtin as the active ingredient, which is repellant in nature and causes high mortality, reduces oviposition and reproduction (Erdogan, 2012). Azadirachtin contains hormone mimicking activities which interferences with the pest lifecycle (Kumar and Navaratnam, 2013). Tick berry leaves contains methanol that has insecticidal activity, contact toxicity and bioactive molecules (Dua *et al.*, 2010)**.** Melia leaves contain volkensin and salannin compounds that prevents the pest from feeding hence stunted and mortality of the pest (Jaoko *et al.*, 2020). Garlic **(***Allium sativum)* contains alliin which is a sulfur containing compound that prevents the pest fromfeeding (Singh *et al.*, 2008).

Most plants are convenient for use due to their abundance, familiarity, safety and farmer's considerable existing knowledge the plants (Stevenson *et al.*, 2012)**.** Crude plant extracts are more viable, effective and eco-friendly hence can efficiently management pest populations as well as reduce pest resistance, increase food security and production capabilities (Adeniyi *et al.*,2010). However, they are not very much effective due to the efficacy variations and their low toxicity and persistence to the targeted pests (Grzywacz *et al.*, 2014) although the need to decrease use of synthetic inputs and enhance practices that promote environmental safety makes them more effective for environmental safety (Sola *et al.*, 2014)**.** The present study evaluates the efficacy of five selected crude plant extracts and their influence in pod borers, whiteflies and aphids' population in green gram crop, hypothesizing that crude plant extracts are effective in the management of pod borers, whiteflies and aphids.

## 4.3 Materials and methods

### 4.3.1 Experimental sites

Experiments were conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) station in Katumani, and in a farmer's field in Katangi, both in Machakos County. Both short rains and long rains seasons were involved in Katumani between October to December 2020 short rains and March to June 2021 respectively and one season, short rains, in Katangi which took place in 2020 between October to December 2020. KALRO Katumani is located 1 $^{o}$34′58″S, 37$^{o}$14′43″E and 1600 m elevation. The mean maximum and minimum temperature in Katangi are 35$^{o}$C and 17$^{o}$C, respectively. Soils of this site are well drained dark red to clay with pH 7.0. The farmers' field in Katangi is located 1$^{o}$40′93″S, 37$^{o}$68′92″E and 1051 m above sea level. Katumani is colder than Katangi with mean maximum temperature of 25 $^{o}$C and minimum 14$^{o}$C. Katangi soils are well drained red brown to clay soils with pH 6.5. Rainfall in both sites have two modes of distribution pattern with a long rains season from March to June and a short season from October to December. Long term data for Katumani shows 382 mm during the long rains season, and 274 in the short season.

### 4.3.2 Treatments and experiment design

Treatments comprised four plant extracts, a positive control of a synthetic pesticide and a negative control of water only. The plant extracts included neem leaves, melia leaves, tick berry leaves and garlic bulb. The synthetic insecticide was Halothrin with active ingredient, lambda-cyhalothrin. Variety N26 of green gram crop was used and sowed within the plots. Treatments were laid out in a randomized complete block design and replicated in three blocks. To account for spatial variation in the experimental fields, the six crude plant extracts were randomly allocated within each of the three blocks of the experiment.

### 4.3.3 Experiment management

In each season, land was tilled prior to onset of rains with a disc plough and harrowed to fine tilth. Crops of green gram were sown at the onset of rains ata spacing of 50cm between rows and 10cm from plant to plant. Plots measured 5m by 5m with 1m alleys between them, and 1.5m between replications. When the crops emerged, cutworms and bean fly were controlled with a single dose of Thunder with active ingredient imidacloprid, and manufactured by Bayer Crop Science AG, Germany, and applied as 10mL/10L water. The pre-harvest interval of imidacloprid is 14 days, and data collection started from 40 days after emergence, hence the chemical did not impact crop infestation by pod borers, whiteflies and aphids. Ridomil with mancozeb as active ingredient, and manufactured by Syngenta Limited in India was applied at 50g/20L water to control bacterial and fungal diseases. A foliar fertilizer of nitrogen, phosphorus and potassium (NPK) and trace elements was applied at 50% branching. Plots were kept weed free by hand weeding.

### 4.3.4 Preparation of plant extracts

Neem, Tick berry, Melia leaves and garlic bulbs were used as they act as antifeedant and inhibitors too to insects' pests (Stevenson *et al.*, 2012). These extracts are well known, abundant and familiar to the farmers (Sunday *et al.*, 2010). Different concentrations of 0.1%,1.0% and 10% w/v have been used and found out that 10% concentrations are very effective to manage pests compared to the other concentrations (Mkindi *et al.*, 2017).

According to Stevenson *et al.*, (2012) making of 10% concentration requires, I kg of the plant extract powder is mixed with 10 liters of water at 15-24 degrees centigrade for 24 hours, 0.1% of soap is added as a sticking agent, the concentration is kept in a 10litre bucket and filtered twice to avoid blockage of the sprayer by plant materials while the plant extractpowder should be stored in black plastic bags under dark and dry conditions and used when needed. Spraying should be done within a 7 days interval after application, using the knapsack sprayer of 5litres and after use, wash it very well with water and soap before refilling with a different formulation (Tembo *et al.*, 2018)**.**

#### 4.3.5 Data collection

Weather data during the growing season was obtained from a weather station near experiment sites, and included daily rainfall, daily maximum and minimum temperate. Assessments on pod borers, aphids and whitefly began four weeks after germination at vegetative stage, 50% floweringand 50% podding of the crop. Data collection was done twice in a week, first before application of the pesticide and three days after application of the pesticides. Actual pest population of pod borers, whiteflies and natural enemies was done through counting number of pod b orers and whitefly which was done on the lower, middle and upper section of the plant and average calculated. Aphid numbers were scored with the use of a 1 -5 scale, where; 0 denoted absence of the pest, 1 meant a few scattered individuals, 2 designated a few isolated colonies, 3 represented several isolated colonies, 4 was large isolated colonies, and 5 signified large continuous colonies (Mkindi *et al.*, 2017) due to aphid's high numbers. For yield data, ten plants were randomly sampledper plo t to determine the number of pods per plant and seeds per pod. Entire plots were harvestedbut with the exception of guard rows, and seed yield expressed in t/ha.

### 4.4 Data analysis

Data were subjected to analysis of variance (ANOVA) to assess the experimental sources of variation using GenStat 15$^{th}$ Edition. A two-way ANOVA routine was used, with replicate (block) and variety as factors, while variables consisted of the collected measurements. Prior to analysis, data was tested for normality and conformed to requirements of ANOVA. Residuals were checked for normal distribution, and no transformations were required. Treatment means were compared and separated using Fisher's least significant difference (LSD) at 5% probability level.

## 4.5 Results

### 4.5.1 Weather data

Weather data involved temperature and rainfall data during 2020 short rains and 2021 long rains. In this study, the two experiment seasons in Katumani and one season in Katangi are referred to as three distinct environments. Rainfall and temperature during the experiment season in the three environments were typical of the two sites as shown in Figure 3.1 in Chapter Three.

### 4.5.2 Effect of crude plant extracts on pest and natural enemies' population

#### 4.5.2.1 Pod borers

The five crude plant extracts and the control treatment showed significant differences (p>0.05) in some stages of the crop within the three different sites (Table 4.1). In Katumani 2020, vegetative stage showed no significant differences but flowering and podding showed a significant difference where pesticide Melia showed the highest pod borer infestation and synthetic pesticide, Lambda_cyhalothrin, showed the least pod borer infestation. In Katangi 2020, vegetative and podding stage showed a significant difference, p>0.05, with control treatment having the highest pod borer infestation and lowest in Lambda_cyhalothrin pesticides. In Katumani 2021, all the crop stages showed a significant different with control treatment showing highest pod borer population while Lambda_cyhalothrin showed the least infestation.

Table 4.1. Mean number of pod borers under different applications of crude plant extracts in green gram crop during vegetative (veg), flowering (flo) and podding (pod) in Katumani and Katangiduring 2020 short rains and 2021 long rains

| | Katumani 2020 | | | Katangi 2020 | | | Katumani 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| Pesticide | Veg | Flo | Pod | Veg | Flo | Pod | Veg | Flo | Pod |
| Neem | 0.3a | 1.3bc | 0.2a | 0.6a | 1.2a | 3.0b | 0.2a | 0.4a | 0.5a |
| Garlic | 0.3a | 1.3bc | 0.1a | 0.5a | 1.1a | 1.7ab | 0.2a | 0.5a | 0.5a |
| Tick berry | 0.3a | 1.1b | 0.2a | 0.4a | 1.0a | 3.3b | 0.4b | 0.7ab | 0.9a |
| Melia | 0.3a | 1.5c | 0.6b | 0.9a | 0.9a | 2.0ab | 0.3ab | 0.9b | 0.9a |
| Lambda_cyhalothrin | 0.2a | 0.7a | 0.1a | 0.5a | 0.8a | 0.5a | 0.2a | 0.4a | 0.5a |
| Control | 0.4a | 1.2b | 0.6ab | 1.2b | 1.3a | 2.6b | 0.6c | 1.5c | 1.8b |
| P Value | 0.055 | 0.001 | 0.010 | 0.016 | 0.391 | 0.018 | 0.001 | 0.001 | 0.001 |
| LSD | 0.12 | 0.20 | 0.17 | 0.07 | 0.45 | 1.66 | 0.19 | 0.26 | 0.70 |
| % CV | 78.6 | 34.7 | 18.6 | 172.9 | 86.2 | 149.7 | 121.4 | 70.0 | 157.8 |

Means followed by the letter within a column are not significantly different

4.5.2.2 Whiteflies

There was a significant difference, p>0.05 between the pesticides and control treatment only under vegetative stage in Katumani 2020 where control treatment and pesticide Tick berry showed highest whitefly infestation and garlic lowest whitefly infestation while Melia and neem showed intermediate whitefly infestation. In Katangi 2020 there was no significant differences between the crude plat extracts among the three stages on whitefly infestation. In Katumani 2021, allthe stages, vegetative, flowering and podding, showed a significant difference, p>0 .05, where tickberry showed highest whitefly population while garlic had the lowest whitefly population (Table4.2).

Table 4.2. Mean number of whiteflies under different applications of crude plant extracts in green gramcrop during vegetative (veg), flowering (flo) and podding (pod) in Katumani and Katangi during 2020 short rains and 2021 long rains

| | Katumani 2020 | | | Katangi 2020 | | | Katumani 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| Pesticide | Veg | Flo | Pod | Veg | Flo | Pod | Veg | Flo | Pod |
| Neem | 0.5a | 0.9a | 1.8a | 0.5a | 0.9a | 1.1a | 0.4a | 0.5a | 0.4a |
| Garlic | 0.3a | 0.8a | 1.7a | 0.5a | 0.8a | 0.8a | 0.6a | 0.3a | 0.3a |
| Melia | 0.4a | 1.1a | 1.9a | 0.4a | 1.7a | 1.0a | 0.8ab | 0.8a | 0.6a |
| Tick berry | 0.9b | 1.0a | 2.0a | 0.5a | 1.9a | 1.0a | 0.6a | 1.0ab | 0.8ab |
| Lambda_cyhalothrin | 0.1a | 0.8a | 1.9a | 0.3a | 0.8a | 0.3a | 0.4a | 0.5a | 0.4a |
| Control | 1.1b | 1.0a | 2.3a | 0.4a | 1.3a | 1.1a | 1.2b | 1.8c | 1.2b |
| P value | 0.002 | 0.783 | 0.859 | 0.838 | 0.062 | 0.579 | 0.014 | 0.001 | 0.001 |
| LSD | 0.38 | 0.49 | 0.96 | 0.41 | 0.85 | 1.08 | 0.49 | 0.54 | 0.47 |
| % CV | 39.2 | 29.2 | 27.5 | 53.4 | 38.6 | 68.0 | 145.8 | 123.6 | 150.8 |

Means followed by the letter within a column are not significantly different

4.5.2.3 Aphids

The applied pesticides showed significant difference in all stages in Katumani 2020 and Katumani 2021 while in Katangi 2020 the flowering and podding stage did not show significant differences. In Katumani 2020 and 2021, under vegetative, flowering and podding stage, control treatment showed highest aphid infestation while garlic pesticide showed the least aphid infestation with neem, lambda-cyhalothrin, Melia and Tick berry showing intermediate aphid infestation. Vegetative stage in Katangi 2020 showed a significant difference, P>0.05, Tick berry showed highest aphid infestation while garlic had the least aphid infestation with neem, Melia, lambda-cyhalothrin and control treatment showing intermediate aphid infestation.

4.5.2.4 Natural enemies

There was a significant difference on the pesticide to natural enemies' incidence in Katumani 2020, Katangi 2020 and Katumani 2021 within the vegetative, flowering and podding stage (Table 4.4). Control treatment had the highest incidence of natural enemies while garlic pesticide showed the least incidence of natural enemies with neem, lambda-cyhalothrin, Melia and Tick berry having intermediate natural enemies' incidence within the three sites during vegetative, f lowering and podding stage.

Table 4.3. Mean number of aphids under different applications of crude plant extracts in green gramcrop during vegetative (veg), flowering (flo) and podding (pod) in Katumani and Katangi during2020 short rains and 2021 long rains

| | Katumani 2020 | | | Katangi 2020 | | | Katumani 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| Pesticide | Veg | Flo | Pod | Veg | Flo | Pod | Veg | Flo | Pod |
| Neem | 0.6b | 0.5a | 0.3a | 0.3a | 0.4a | 0.7a | 0.2a | 0.4a | 0.4a |
| Garlic | 0.2a | 0.5a | 0.2a | 0.2a | 0.7a | 0.6a | 0.3a | 0.3a | 0.3a |
| Melia | 0.7b | 1.0b | 0.6b | 0.4a | 0.4a | 0.4a | 0.2a | 0.7b | 0.7ab |
| Tick berry | 0.6b | 0.3a | 0.1a | 0.9b | 0.4a | 0.6a | 0.4a | 0.8b | 0.9b |
| Lambda_cyhalothrin | 0.5a | 0.3a | 0.4a | 0.3a | 0.8a | 0.5a | 0.3a | 0.7b | 0.8b |
| Control | 1.1c | 1.0b | 1.0c | 0.8a | 0.9a | 0.6a | 0.9b | 1.7c | 1.3c |
| P value | 0.015 | 0.023 | 0.001 | 0.006 | 0.159 | 0.822 | 0.001 | 0.001 | 0.001 |
| LSD | 0.40 | 0.47 | 0.23 | 0.34 | 0.46 | 0.55 | 0.28 | 0.35 | 0.40 |
| % CV | 37.0 | 44.7 | 29.6 | 39.8 | 41.9 | 55.0 | 144.8 | 92.5 | 107.3 |

Means followed by the letter within a column are not significantly different

Table 4.4. Mean number of natural enemies under different applications of crude plant extracts in green gram crop during vegetative (veg), flowering (flo) and podding (pod) in Katumani and Katangi during 2020 short rains and 2021 long rains

| | Katumani 2020 | | | Katangi 2020 | | | Katumani 2021 | | |
|---|---|---|---|---|---|---|---|---|---|
| Pesticide | Veg | Flo | Pod | Veg | Flo | Pod | Veg | Flo | Pod |
| Neem | 0.3a | 1.3b | 1.3a | 0.3a | 0.7ab | 0.4a | 3.6a | 1.8a | 2.1a |
| Garlic | 0.1a | 0.7a | 1.3a | 0.1a | 0.3a | 0.7a | 2.9a | 1.8a | 1.6a |
| Melia | 0.3a | 1.0a | 0.7a | 0.7ab | 1.3ab | 0.3a | 3.4a | 3.6ab | 4.6b |
| Tick berry | 2.8b | 1.0a | 2.3ab | 2.3b | 1.0b | 1.0a | 3.3a | 4.2b | 4.1b |
| Lambda_cyhalothrin | 0.7a | 1.3b | 0.7a | 1.3ab | 0.3a | 0.7a | 2.6a | 2.8ab | 2.3a |
| Control | 5.0c | 5.3c | 4.3b | 5.0c | 5.0c | 5.3b | 7.3b | 7.1c | 6.9c |
| P Value | 0.001 | 0.001 | 0.024 | 0.003 | 0.023 | 0.012 | 0.002 | 0.004 | 0.001 |
| LSD | 1.69 | 1.71 | 2.11 | 2.06 | 2.69 | 2.75 | 1.80 | 2.29 | 1.33 |
| % CV | 62.1 | 53.0 | 65.5 | 70.5 | 102.4 | 118.4 | 25.8 | 35.7 | 20.4 |

Means followed by the letter within a column are not significantly different

4.5.2.5 Pod damage percentage (%)

Pod damage percentage (%) showed significant differences across the three sites. Among the plant extracts, melia and tick berry showed highest pod damage percentage while garlic and neem showed lowest pod damage. In overall, control treatment showing the highest pod damage percentage while Lambda-cyhalothrin synthetic showed lowest pod damage percentage.

Table 4.14. Pod damage percentage (%) of green gram under different applications of crude plant extracts in Katumani and Katangi during 2020 short rains and 2021 long rains

| Pesticides | Katumani 2020 | Katangi 2020 | Katumani 2021 |
|---|---|---|---|
| Neem | 47a | 57b | 63ab |
| Garlic | 40a | 37a | 53ab |
| Melia | 70b | 77ab | 90c |
| Tick berry | 70b | 73b | 77bc |
| Lambda_cyhalothrin | 43a | 40a | 43a |
| Control | 83b | 80b | 93c |
| P Value | 0.001 | 0.012 | 0.009 |
| LSD | 17.47 | 26.08 | 26.36 |
| % CV | 16.3 | 23.7 | 20.7 |

Means followed by the letter within a column are not significantly different.

4.5.3 Yield components

4.5.3.1 Number of pods per plant and seeds per pod

There was no significant different between the pesticides to number of pods per plant and numbers of pods per pod in Katumani 2020, Katangi 2020 and Katumani 2021. (Table 4.6). The three sites showed non-significance differences, $p<0.05$, between the two parameters.

4.5.3.2 Seed yield and 100 seed weight

Seed weight (100) showed significant differences to crude plant extracts with Tick berry having highest seed weight while neem showed highest seed weight with Melia and Garlic having median seed weight across Katumani 2020 and Katangi 2020 sites while in Katumani 2021 no significant differences were observed. (Table 4.7). Yield showed significant differences in Katumani 2020 and Katumani 2021 between the four plant extracts, Lambda-halothrin pesticides and control treatment but no significant differences between the plant extracts was observed, in Katangi 2020 there was no significant difference in yield between all the treatments (Table 4.7).

Table 4.15. Mean number of pods per plant and seeds per pod of green gram under different applicationsof crude plant extracts in Katumani and Katangi during 2020 short rains and 2021 long rains

| Pesticide | Number of pods per plant | | | Number of seeds per pod | | |
|---|---|---|---|---|---|---|
| | Katumani 2020 | Katangi 2020 | Katumani 2021 | Katumani 2020 | Katangi 2020 | Katumani 2021 |
| Neem | 49.2a | 25.6a | 9.0a | 12.0a | 10.9a | 9.9a |
| Garlic | 46.1a | 21.9a | 8.0a | 12.7a | 9.8a | 10.6a |
| Melia | 37.8a | 25.0a | 8.1a | 12.2a | 9.5a | 10.1a |
| Tick berry | 43.6a | 19.8a | 10.5a | 11.7a | 9.8a | 9.8a |
| Lambda_cyhalothrin | 40.9a | 21.9a | 10.0a | 12.1a | 10.3a | 10.6a |
| Control | 41.2a | 20.7a | 8.5a | 11.7a | 10.1a | 10.2a |
| P value | 0.587 | 0.210 | 0.122 | 0.514 | 0.384 | 0.600 |
| LSD | 13.17 | 5.39 | 3.41 | 1.12 | 1.33 | 1.06 |
| % CV | 59.9 | 47.0 | 57.7 | 18.3 | 25.9 | 20.4 |

Means followed by the letter within a column are not significantly different

Table 4.16. Mean yield and 100 seed weight of green gram under different applications of crude plant extracts in Katumani and Katangi during 2020 short rains and 2021 long rains

| Pesticide | 100 seed weight (g) | | | Yield (t/ha) | | |
|---|---|---|---|---|---|---|
| | Katumani 2020 | Katangi 2020 | Katumani 2021 | Katumani 2020 | Katangi 2020 | Katumani 2021 |
| Neem | 6.0a | 4.7a | 5.0a | 3.3a | 4.3a | 0.2a |
| Garlic | 5.8a | 4.8a | 4.7a | 3.8a | 3.6a | 0.5a |
| Melia | 5.7a | 4.8a | 4.9a | 3.1a | 4.6a | 0.3a |
| Tick berry | 6.7b | 5.4b | 4.7a | 3.8a | 4.2a | 0.3a |
| Lambda_cyhalothrin | 6.8b | 4.5a | 4.9a | 4.6b | 4.5a | 1.0b |
| Control | 6.1a | 4.8a | 4.9a | 3.7a | 4.5a | 0.1a |
| P Value | 0.001 | 0.001 | 0.930 | 0.040 | 0.695 | 0.041 |
| LSD | 0.52 | 0.35 | 0.74 | 0.88 | 1.86 | 0.45 |
| % CV | 9.0 | 7.0 | 8.3 | 13.1 | 24.7 | 66.0 |

Means followed by the letter within a column are not significantly different.

## 4.6 Discussion

### 4.6.1 Effect of crude plant extracts on pest population

Data showed that plant extracts were effective in controlling pod borers, whiteflies and aphids in green gram. However, garlic showed higher efficacy over the other plant extracts against the three major pests. The present study did not measure mechanisms operating under each of the crude plant extract but reports show that the key effects result from repellence, antifeedant and death of the insect. For instance, garlic contains thiosulfate allicin, a volatile sulfur component with a distinct smell and taste which causes substantial mortality and repellency to pest larva, pupa and even adults (Keusgen, 2011). According to Plata-Rueda *et al.* (2017), garlic compounds are a potential source of insecticidal components which warrants further destructions to the pests because insects exposed to garlic concentrates showed, behavioral deterrence and repellency as well as alteration in locomotion activities, muscle contractions due to disruption of the respiratory system (Upadhyay and Jaiswal, 2007; Rahman *et al.*, 2016).

Neem was found to be effective in the management of the pests in this study, and present results corroborate findings on neem-based biopesticides (Rasoul *et al.* 2012). Ivbijaro and Bolaji (1990) found that *indica* based products to be efficient than synthetic pesticides in the management of whiteflies and aphids. Neem contains azadirachtin which is known to reduce pest population through antifeedant effects and impairs digestion (Sola *et al.*, 2014). In addition, neem extracts have highly developed intricate chemical fortification against insect pest attack and are biologically rich in active chemical compounds potent in protecting the crops for insect pests (Adedire and Akinneye, 2005). Ugwu (2020) argues that neem derivatives provide a broad spectrum for the management of over 200 species of phytophagous pests.

Melia was also found to be effective in the management of pod borers, whiteflies and aphids in this study. Melia contains ethanol which is an effective feeding deterrent and a growth disruptor (Hammad and Mcauslane, 2006). Further, Mitchel *et al.* (2004) measured reduced green stink bug population, potentially due to developmental abnormalities like malformed wings, scutellum, legs and antennae, growth disruption and antifeedant effects on the pest.

Tick berry results showed management of pests under this study which is in agreement with (Ayalew, 2020) whose study found out that tick berry, reduces pest population through repellant and toxic effect with active biochemical molecules. (Isman *et al.* (2011)**,** concluded that tick berry also has both insecticidal and fumigant properties like piperidine, ethoxy and pyrolline whereby once they enter the insect body they lead to biochemical dysfunction and reduced reproduction as well as growth disruption and pest mortality (Mahboubi and Farzin, 2009). Tick berry also contains rotenoids, limonene and phellandrene, which are well known to have anti-insect and insecticidal properties that hinders pests from feeding, oviposition, stunted growth and even death (Singh and Singh, 2008). Tick berry causes larval death during its early stages due to disruption of the larvae metamorphosis through its antifungal properties (Bartolome *et al.* 2013).

### 4.6.2 Effect of crude plant extract on natural enemies

Natural enemies were less affected by the crude plant extracts compared to synthetic insecticide. Studies show that plant extracts have a low toxicity and persistence on the ecosystem due to their rapid degradation (Singh and Singh, 2008). Evidence demonstrates a wide range of negative effects of synthetic pesticides on natural enemies, the environment as well as human heath (Ecobichon, 2001). These effects not only result from the constituent active ingredient but also from injudicious use. Despite plant extracts' efficacy and low negative effects on natural enemies (Sola *etal.*, 2014) their use remains low due to high logistical costs in their preparations.

### 4.6.3 Effect of crude plant extracts on green gram yield

Despite a higher number of insect population on crops applied with crude plant extracts compared with counterparts sprayed with a synthetic insecticide, there were no differences in seed yield. This could be attributed to reduction in pest numbers through natural enemies and tolerance of the crop species to a certain amount of damage, which the crop can physiologically compensate to maintain the overall yield (Brown, 2005) by ensuring that the crop is in good health. Higher yields could be associated with crop compensation through the frequent application of the pesticidal plant extracts which could have provided the crop with protection from diseases (Rasoul *et al.*, 2012; Sharma *et al.*, 2005).

## 4.7 Conclusion

Crude plant extracts showed significant reduction of pest infestation in green gram. Neem and garlic plant extracts revealed highest impact on pod borers, whiteflies and aphids' population compared with tick berry and Melia plant extracts. Further understanding on the neem and garlic active ingredient application rate, concentration application and durability is necessary for effective pest management.

# CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

## 5.1 General discussion

Crop phenology and morphological traits significant affect pest population in crops. Green gram varieties varied significantly in crop phenology where variety KS20 mature earliest while N26 was late, and the other varieties were intermediate. Leaf area influenced pest numbers through provision of area for pest to feed, movement as well as multiply as seen in varieties that had a higher leaf area (Martin *et al.*, 1996). Leaf hairs interferes with pest movement which affects pest feeding and mating, varieties that showed higher leaf hair density showed less pest numbers compared to varieties that showed a lower leaf hair density (Rustamani *et al.*, 2014). Among the new varieties, Biashara, showed more superior morphological traits compared to the rest while with the old varieties, KS20, showed more superior morphological and agronomic traits. According to Halder *et al.* (2006), these variations in phenology and morphological traits could be attributed to different evolutionary pathways of development and genetic variations of the varieties. Interaction between the varieties and the environment are important in instances and could be used to explain the observed variations.

Pest numbers varied significantly among the varieties in both sites. This could be attributed to the variety's growth period or crop phenology and the crop morphological traits. Green gram varieties that showed highest pest numbers matured late and had inferior morphological traits while varieties that showed lowest pest numbers showed early maturity and superior morphological traits, like high leaf hair density and a thick pod wall. Early maturity, high leaf hair density, leaf area and pod wall showed decreases pest numbers while late maturity, leaf area and leaf moisture increase pest numbers (Zia *et al.* 2011). Specifically, aphids and whiteflies are known sucking pests (Quandahor *et al.* 2019) hence varieties leaf moisture content influenced the pests' numbers in that varieties with low moisture content showed highest pest numbers and vice versa through provision of sap for the pests to feed. Pod wall thickness influences pest, pod borer, numbers through interfering with its penetration to feed in the seed (Rahman *etal.*, 2016). Comparing the old and new varieties, N26, showed highest pest numbers among the new varieties while Karembo showed highest pest numbers among the new varieties. This clearly shows how crop phenology and morphological traits are mechanisms that can be used to management pest numbers as well as breeding options for varieties with high pest resistance.

Crude plant extracts varied significantly across the two sites on pet numbers and level of infestation, some crude plan extracts showed lowest pest numbers on the target pests but negatively impacted the beneficial organisms while some crude plant extracts showed highest numbers of target pests without affecting the beneficial organisms. This observation could be attributed to the different insecticidal properties and active ingredients of the crude plant extracts (Bartolome *etal*., 2013). Different plant extracts were used and had different influence on the pests which are known to have less pest resistance, environmental and human safety as well as low cost and more familiarity compared to synthetic pesticides. Garlic contains alliin, which has both repellent ad biocidal properties, the sulfur in alliin repels and drives away pest from the crops (Mahboubi and Farzin, 2009). Neem contains azadirachtin as the active ingredient which acts as an antifeedant, repellent and induces sterility in pests (Singh and Singh, 2008). Melia is known to be a growth inhibitor and contains antifeedant properties against pests while berry contains a methanol active ingredient which has fumigant which acts as a repellent and contact toxicity leading to death of the pests (Sola *et al*., 2014).

Pod damage percentage variations were significantly observed across the crude plant extracts within the two sites. The crude plant extracts had different damage levels on the pests which can be attributed to their different antifeedant and insecticidal properties of the plant extracts that influenced feeding and infestation of the pests on the crop (Hammad and Mcauslane, 2006).

Yield varied significantly among the green gram varieties within the two sites, this includes number of pods per plant, numbers of seeds per pod, seed weight and the average yield per variety. Variations in yield components could be attributed to levels of pest numbers and infestation on the different varieties (Duke, 2020). Some varieties showed highest number of pods per plant, seeds per pod as well as the net yield and vice versa. Variations were also significantly observed in yield among the plant extracts. Plant extracts with lowest pest numbers showed highest yield components extract while plant extracts with highest pest numbers showed lowest yield components. Hammad and Mcauslane (2006) found out the variation in yield could be associated with developmental stages of the crop and the morphological traits of the crop, in that, varieties that showed highest yield components matured early and their morphological traits negatively affected the pet survival and infestations on the crops. This clear shows how differently crop morphological traits and plant extracts can influence pest infestation and both assimilated into pest management as biological control options.

## 5.2 Conclusion

Green gram varieties varied significantly on the morphological traits while the response of crude plant extracts on the pest number, pod damage percentage and yield varied significantly. Variety KS20 and Biashara recorded superior morphological traits for leaf hair density, leaf area as well as leaf moisture content hence maybe used in the development of improved green gram varieties, Neem and garlic crude extracts showed less pest numbers, low pod damage percentage and high yield. The significant variations especially in quantitative traits like leaf hair density observed among the varieties from the sites presents a great possibility for the development of suitable varieties for various agro-ecological zones. The effectives of both neem and garlic plant extracts on pest management, safety on the environment and non-target shows that plant extracts can manage pests. The observed variations under morphological traits in varieties and plant extracts in pest and natural enemies clearly shows how both, crop morphological traits and plant extracts, can be incorporated in integrated pest management techniques to enhance food production and reduce pest infestation.

## 5.3 Recommendations

- Varieties that showed significant differences in morphological traits such as KS20 and Biashara could be explored in enhancing varietal resistance
- Long-term evaluation of the potency of crude plant extracts on green gram field pests is required
- Further studies are required to calibrate the optimal dosage rates of the studied crude plant extract

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**APPENDICES**

Appendix 1. Analysis of variance of crop phenology (maturity) in Katumani 2020 short rains season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 17.733 | 8.867 | 5.22 | |
| Rep.*Units* stratum | | | | | |
| Var | 4 | 695.600 | 173.900 | 102.29 | <.001 |
| Residual | 8 | 13.600 | 1.700 | | |
| Total | 14 | 726.933 | | | |

Appendix 2. Analysis of variance of pod borer number during podding in Katangi 2020 short rains season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 0.0505 | 0.0252 | 0.05 | |
| Rep.*Units* stratum | | | | | |
| Var | 4 | 43.5711 | 10.8928 | 21.81 | <.001 |
| Residual | 8 | 3.9960 | 0.4995 | | |
| Total | 14 | 47.6175 | | | |

Appendix 3. Analysis of variance of whitefly numbers during flowering in Katumani 2021 long rain season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 0.23333 | 0.11667 | 1.26 | |
| Rep.*Units* stratum | | | | | |
| Var | 4 | 0.31400 | 0.07850 | 0.85 | 0.533 |
| Residual | 8 | 0.74000 | 0.09250 | | |
| Total | 14 | 1.28733 | | | |

Appendix 4. Analysis of variance of leaf area during flowering (Katumani 2020) short rain season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 6.927 | 3.463 | 0.64 | |
| Rep.*Units* stratum | | | | | |
| Var | 4 | 984.661 | 246.165 | 45.15 | <.001 |
| Residual | 8 | 43.620 | 5.453 | | |
| Total | 14 | 1035.209 | | | |

Appendix 5. Analysis of variance of leaf hair numbers during vegetative crop stage during Katangi 2020 short rain season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 1.785 | 0.893 | 0.36 | |
| Rep.*Units* stratum | | | | | |
| Var | 4 | 7606.547 | 1901.637 | 762.13 | <.001 |
| Residual | 8 | 19.961 | 2.495 | | |
| Total | 14 | 7628.293 | | | |

Appendix 6. Analysis of variance of leaf moisture content during Katangi 2020 short rain season

| Source of variation | d.f. | s.s. | m.s. | v.r. |
|---|---|---|---|---|
| rep stratum | 2 | 36.113 | 18.057 | 3.94 |
| rep.*Units* stratum | | | | |
| variety | 4 | 11.453 | 2.863 | 0.62 |
| Residual | 8 | 36.708 | 4.588 | |
| Total | 14 | 84.274 | | |

Appendix 7. Analysis of variance of number of pods per plant during Katumani 2021 long rain season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 11.530 | 5.765 | 1.86 | |
| Rep.*Units* stratum | | | | | |
| Var | 4 | 92.306 | 23.076 | 7.43 | 0.008 |
| Residual | 8 | 24.832 | 3.104 | | |
| Total | 14 | 128.669 | | | |

Appendix 8. Analysis of variance of yield during Katangi 2020 short rain season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 1.5171 | 0.7585 | 2.76 | |
| Rep.*Units* stratum | | | | | |
| Var | 4 | 24.5933 | 6.1483 | 22.37 | <.001 |
| Residual | 8 | 2.1987 | 0.2748 | | |
| Total | 14 | 28.3091 | | | |

Appendix 9. Analysis of variance of number of whitefly during vegetative crop stagein Katangi 2020 short rain season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 0.05790 | 0.02895 | 0.55 | |
| Rep.*Units* stratum | | | | | |
| Pesticide | 5 | 0.10568 | 0.02114 | 0.40 | 0.838 |
| Residual | 10 | 0.52728 | 0.05273 | | |
| Total | 17 | 0.69086 | | | |

Appendix 10. Analysis of variance of aphid's number during flowering crop stage in Katumani 2021 long rain season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 0.13083 | 0.06542 | 2.83 | |
| Rep.*Units* stratum | | | | | |
| Pesticide | 5 | 3.61542 | 0.72308 | 31.27 | <.001 |
| Residual | 10 | 0.23125 | 0.02312 | | |
| Total | 17 | 3.97750 | | | |

Appendix 11. Analysis of variance on number of natural enemies during flowering in Katumani 2020 short rain season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 6.3333 | 3.1667 | 4.13 | |
| Rep.*Units* stratum | | | | | |
| Pesticide | 5 | 44.5000 | 8.9000 | 11.61 | <.001 |
| Residual | 10 | 7.6667 | 0.7667 | | |
| Total | 17 | 58.5000 | | | |

Appendix 12. Analysis of variance of pod damage percentage (%) in Katumani 2021 long rain season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| rep stratum | 2 | 33.3 | 16.7 | 0.08 | |
| rep.*Units* stratum | | | | | |
| Pesticide | 5 | 6066.7 | 1213.3 | 5.78 | 0.009 |
| Residual | 10 | 2100.0 | 210.0 | | |
| Total | 17 | 8200.0 | | | |

Appendix 13. Analysis of variance of yield in Katangi 2020 short rain season

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| Rep stratum | 2 | 2.768 | 1.384 | 1.32 | |
| Rep.*Units* stratum | | | | | |
| Pesticide | 5 | 3.192 | 0.638 | 0.61 | 0.695 |
| Residual | 10 | 10.457 | 1.046 | | |
| Total | 17 | 16.417 | | | |