EVALUATION OF RESISTANCE OF SELECTED GREEN GRAM (*Vigna radiata*) VARIETIES AGAINST INSECT PESTS INFESTATION DURING LONG RAINS SEASON, THARAKA NORTH AND SOUTH SUB-COUNTIES, KENYA

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and has not been presented for a diploma or degree in any other institution or university

Signature……………………….. Date……………………………...

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Recommendation

This thesis has been examined, passed and submitted with our approval as the University supervisors

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DEDICATION

I dedicate this work to my father Nicholaus Musyoki, my mother Jeniffer Makiah, and my daughter Westley Hope Mwende for always encouraging and supporting me and for their unfailing love.

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ABSTRACT

Green grams farming plays a vital role in Tharaka Nithi County and the country at large by ensuring food security, creating employment for rural households and greatly contributing to the national economy. However, the infestation of insect pests on the green grams has drastically affected its production in the country and therefore the current study seeks to identify the green gram variety that can resist insect pests for better productivity. This study was conducted in Mukothima and Gatunga wards in Tharaka North and Tharaka South Sub-counties during one growing season between March-May, 2023, the period of long rains. The study presents insect pests attacking greens in the field, the most resistant green gram variety among the selected varieties and the relationship between insect pest infestation and overall yields. Sticky insect traps were set to capture pests, manual counting of pests and a dissecting microscope were used to count minute insect pests. Levels of leaves and pod damages were also checked and the resulting yield was weighed using a weighing balance. Whiteflies and aphids were the major pests in the green grams with African pod borers and leaf weevils causing insignificant levels of damage (Whiteflies-Uncle-334.3, Biashara-446.33, Karembo-352.8, Tosha- 420, Nylon- 515.7; Aphids- Uncle-323.9, Biashara-459.6, Karembo-394.5, Tosha- 413.6, Nylon- 468.8). The levels of damage on leaves and pods recorded were as follows; Nylon (severity of leaves damage-1991.0, incidence of pods damage- 0.328, number of holes poked in leaves- 3.11) proved to be the most resistant to whiteflies and aphids and Ndengu Tosha (severity of leaves damage-2564.76, incidence of pods damage-0.599, number of holes poked in leaves-4.45) the least resistant to whiteflies and aphids. The relationship between insect pest infestation and yields showed that an increase in the number of insect pests led to a decrease in yields. Some varieties' yields were affected by whiteflies, others by aphids and others by both (Karembo-aphids (0.3935), Uncle- aphids (0.525), Biashara- whiteflies (0.2033), Nylon- none, Tosha- whiteflies (0.407) and aphids (0.297)). All the means of the analyzed data were separated using Tukey's HSD (Tukey's Honestly Significant Difference Test) at 5% significance. In conclusion, insect pests (whiteflies and aphids) cause significant levels of losses in green gram which differ in different varieties (Nylon having the least yield loss and Tosha having the highest loss in yield). There is a need to breed varieties that are resistant to whiteflies and aphids. The results of the study are useful in variety selection during planting to minimize losses caused by insect pests and advise KALRO on the best variety.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACZ	Agroclimatic Zone
AFB	African Pod Suck Borers
ANOVA:	Analysis of Variance
ASAL:	Arid and Semiarid Lands
ASL:	Above Sea Level
BIASH:	Biashara
BT:	*Bacillus thuringiensis*
CG:	Compensatory Growth
CRISPR:	Clustered Regularly Interspaced Short Palindromic Repeats
HSD:	Honestly Significant Difference Test
KALRO:	Kenya Agricultural and Livestock Research Organization
KAREM:	Karembo
NACOSTI:	National Commission for Science, Technology and Innovation
NGOs:	Non-Governmental Organizations
OND:	October, November and December season
RCBD:	Randomized Complete Block Design
S.L:	Severity of Leaf Damage
SEM:	Standard Error of Means

CHAPTER ONE
INTRODUCTION

1.1 Background Information

Green grams (*Vigna radiata*), also known as mung beans (Nadig *et al.*, 2021), 'ndengu' (Kiswahili) and 'nkina'(kitharaka, the native language) planted in semi-arid areas of Tharaka North and Tharaka South Sub-counties and Mwingi are of high nutritive value (proteins-14.2g, carbohydrates-38.8g, fats-0.8g, fibre-15.4g, sugar-4g, calories-212) (Sozer *et al*., 2017); (Mucioki *et al*., 2018).

Cultivation of green grams encounters many challenges such as diseases, poor agronomic practices, drought and pests (Nair *et al.*, 2019). These affect the general performance of the crops and consequently lead to low production. Some of the diseases affecting green grams include; bacterial leaf blight, anthracnose, cercospora leaf spot, mung bean yellow mosaic virus, rust, powdery mildew, root rot and leaf blight (Wambua *et al.*, 2017). Poor agronomic practices include poor soil management where soils are not checked for proper nutrients that help the green grams grow at optimum conditions. Additionally, untimely routine practices like weeding, pest and disease management affect green gram production (Latha *et al.*, 2018). Drought causes a decrease in shoot and root development, the leaf area becomes small and therefore photosynthesis is also reduced, uptake of nutrients and translocation which is aided by water is also (Daryanto *et al.*, 2015). Insect pests known to affect this crop include; cutworms, aphids, root-knot nematode, pod-sucking bugs, pod-borers, red-spider mites and spiny pod borer (Meena and Dudi, 2018). These insect pests affect crops at different developmental stages and affected parts include roots, leaves, flowers and pods (Parween *et al.*, 2016). They cause an average of 80-100% yield loss and affect seed quality depending on the intensity of infestation and pest type (Kilimo Trust 2017).

Green gram cultivation in America encounters competition from other legume crops like soybeans, black beans, and chickpeas which are more extensively cultivated and have established markets (Karthikeyan *et al.*, 2014). Limited awareness, climate suitability and less demand for green grams in America affect production levels. Green grams play a vital role in providing nutrition and dietary diversity in the area.

In India, where green grams originated, approximately sixty-two (62) types of bugs have been recorded, yet just a few groups cause monetary harm (Vir *et al.*, 2016). The important bugs infesting green grams are whiteflies, jassids, thrips, pod-sucking bugs, unit drills, stem flies and aphids (Nurunnabi, 2009). Nymphs and adult stages of jassids as well as white flies (Singh *et al.*, 2019a) are responsible for hopper burns, cell enlargement and a decrease in crop yields (Nair *et al.*, 2018). They also upset nutrient translocation and impede photosynthesis thus hindering crop development and making them susceptible to diseases (Ammar *et al.*, 2013). Many studies have also been carried out on storage insects that attack green grams in the country, like the *Callosobruchus chinensis* (Chinese bruchid) which results in decreased yield quality and quantity (Singh and Boopathi, 2022). Field pest studies have been done in India where the study focuses on the identification and control measures of white flies using synthetic chemicals and biopesticides (Singh *et al.*, 2020).

Green gram farming in Nigeria helps both farmers and customers in terms of nutrition and finances (Joshi and Rao, 2017). For smallholder farmers in Nigeria, green gram cultivation has the potential to increase food security, nutrition, and revenue production with the correct assistance, such as better access to seeds and instruction in modern agricultural methods (Nassary *et al.*, 2019).

In Uganda, green grams are most often grown in the eastern, northern, and central parts of the nation. They are highly prized for their nutritional qualities, especially their seeds, which constitute a crucial element of Ugandan diets and are protein-rich. Insect pests challenging green gram production include whiteflies, thrips, aphids, bean beetles, leaf hoppers and pod borers among others. Mung bean production in the country is still low estimated at less than 300 kg/ha due to a number of obstacles, including lack of access to improved varieties, disease and insect pest issues, low-yielding varieties, prolonged maturing varieties, variable climatic and soil conditions as well as poor crop management practices.

In Kenya, many studies have been done concerning field insect pests in green gram in arid areas and arid, semi-arid and medium-high rainfall areas. Common insect pests affecting green gram production include flower thrips, pod borers, aphids, whiteflies, pod-sucking bugs and foliage beetles among others. The rate of losses (50-90%) caused by these pests is dependent on the type of insect infesting the green gram and the rate of infestation. The type of pests in the country is also seasonal and locational determined (Sharma *et al.*, 2015). Different varieties are preferred by different insect pests depending on palatability preference. Some varieties are more resistant to insect pests compared to others. Many studies involving field and storage pests have also been done and are vital in reducing losses attributed to pests which ultimately lead to decreased productivity and consequently affect all other benefits associated with green grams (Karuppuchamy and Venugopal, 2016). The current increase in temperatures due to global warming favors an increase in the number of insect pests due to their increased reproductivity (Skendžić *et al.*, 2021).

Different insecticides have been developed in Kenya by various firms to counteract the attack of crops by insects. Some of the insecticides used include; dimethoate, wadudukiin, actellic, and duduthrin (trade names) among others from different companies and they are locally available. However, these insecticides have negative effects like affecting organisms' survival, survival ability and developmental changes among others to the environment and biota (Mahmood *et al.*, 2016).

Outcomes on investigations concerning factors contributing to insect pest resistance to new and old green gram varieties from KALRO Katumani revealed that there were no specific traits demonstrating that new varieties could have been improved for pest resistance. assessed the preferred green gram lines with reference to maturity, seed size, yield and drought resistance not considering the crucial aspect of pest resistance (Mulwa *et al.*, 2023a) and (Karimi *et al.*, 2019).

The present study sought to evaluate insect pest-resistant green gram varieties since the newly released varieties await validation. Insect pest resistance among the newly released and the old varieties were compared to establish the most resistant variety among the planted varieties during the study.

1.2 Statement of the Problem

The recent rise in temperatures provides a conducive environment for insect pest reproduction. Insect pests lead to significant damage to green grams, a major food and cash crop in the growing regions. They lead to impaired development and significant yield losses (50-90%) dependent on the type of insect pests and the rate of attack. These have greatly resulted in poverty leading to school dropouts and malnutrition (Gioto, 2018). The development of pest-resistant varieties is one strategy that has been adopted to reduce the damage to crops and yield losses. Based on this strategy, KALRO recommended new varieties which were supposedly released to counter the challenge of insect pests' infestation compared to the old varieties (for validation). The results of this study will be recorded among the validation studies carried out on the released varieties. The study compared the insect pest resistance capabilities of the released varieties with the old varieties to establish the most resistant variety.

1.3 Objectives

1.3.1 General Objective

To evaluate the resistance, performance and overall yield of selected green gram varieties in response to insect pest infestation in the field for food security in Kenya.

1.3.2 Specific Objectives

i. To identify various field insect pests affecting green grams in Tharaka North and Tharaka South Sub-counties.
ii. To determine green gram variety resistance to insect pest infestation.
iii. To investigate the effects of insect pest infestation on green grams' overall yield

1.4 Hypothesis

H_{o1} There are no insect pests affecting green grams in the field.

H_{o2} There is no significant difference in insect pest resistance among the selected green gram varieties to be evaluated against insect resistance.

H_{o3} There is no significant difference in the relationship between insect pest infestation and yield among the selected green gram varieties.

1.5 Justification

More than 70% of farmers grow green grams in Tharaka North and Tharaka South Sub-counties (Demissie *et al.*, 2019). Being the main cash crop, it is of major economic importance to people in Tharaka handling major economic aspects including paying school fees thus reducing school dropout rates region (Karimi *et al.*, 2019). In addition, due to its nutritive value, it has components like protein, iron and folate important in reducing malnutrition in the community. Insect pests are known to affect the production of green grams causing approximately 80-100% yield losses annually and globally. Different methods of eradicating these insects have been identified including the use of insecticides which have posed a risk to human health, proved environmentally inimical and costly with one liter of Waduduklin costing approximately one thousand five hundred Kenyan shillings for half an acre of land (Constantine *et al.*, 2020). Therefore, farmers who cannot afford to purchase these chemicals are at great risk of losing a lot of yields and consequently a lot of money due to damage from the insect pests. However, efforts to evaluate the best variety that will be resistant to the attack of these insect pests have not been fully ventured. The new varieties that were released by Kenya Agricultural and Livestock Research Organization are still under validation on the ability to resist insect pests and therefore, this study will be recorded among the validation studies on these varieties. This study evaluated varieties developed by KALRO and determined resistant varieties that when used by green gram farmers in Tharaka and those from other communities will lead to increased yields of high quality with low cost of production. Identifying these varieties also helps the country towards achieving some of its sustainable development goals including zero hunger, no poverty, decent work and economic growth, life below water and life on land among other goals.

CHAPTER TWO
LITERATURE REVIEW

2.1 Overview of Green Grams

The source of green gram certified seeds in all the eight counties that grow green grams in Kenya is the Kenya Agricultural and Livestock Research Organization (KALRO) (Nyongesa *et al.*, 2017). The farmers get these seeds from the distribution by the County Government as well as from privately owned Agro-dealers. Some counties such as Makueni receive seed distribution from NGOs and other partners (Sperling *et al.*, 2021). Farmers mostly recycle the previous season's seeds as planting materials, this affects the green gram yield per acre because of the reduction in the superiority of seeds over time. One of the challenges identified in almost all the counties is the mushrooming of various seed distributors who have been supplying sub-standard seeds thereby affecting the yields (Chamberlain and Anseeuw, 2017). This is an indication of the presence of an unregulated market due to a lack of legislation and where they exist, failure to enforce it.

There are two common varieties of green grams noted across all inspected counties; Uncle (KS20) and Nylon (N26). KS20 was noted as advantageous over N26 because it is shiny and cooks fast hence local people lean towards it while the former is valued for the product market. The cost for the KS20 affirmed seed is additionally higher than that of N26. The cost of a 2kg pack of KS20 varies from KES 500 to KES 600 while that of N26 goes from KES 480 to KES 550 (Muindi, 2019a). There are also three new assortments of green grams that have been released. They include ndengu Tosha (KAT 00301), Bishara (KAT 00308) and Karembo (KAT 00309) though they have not yet gained popularity in these areas. Farmers' benefits include seeds, sponsorship of farm trucks for furrowing and credits in the green gram growing countries including Kitui, Embu, Makueni, Machakos, Meru and Kirinyaga (Wambua *et al.*, 2019).

2.1.1 Ecological Conditions for Growing Green Grams in the Field

Green grams flourish in soil that is well drained, wealthy in nutrients and with an ideal pH of 6.0-7.5 (Mbaka, 2020). Plants develop premier at an altitude of 0-1600M ASL (Mitra and Sharma, 2020). An optimum temperature of between 28-30 degrees Celsius is appropriate for green gram development. Crop development and advancement are greatly influenced by outrageous temperatures (Mitra and Sharma, 2020). Green grams are generally tolerant to drought and can give sensible yields with a yearly precipitation of between 350-650mm (Demissie *et al.*, 2019). Excessive downpours or long droughts generally diminish yields. Unnecessary precipitation during blossoming causes bloom abortion whereas low precipitation is significant during collecting or harvests. Propagation of green grams is done using seeds that ought to be certified or infection free avoiding harmed or wilted seeds.

2.1.2 Planting of Green Grams

A land with well-drained sandy to loamy soils is the most preferred for growing green grams (Mugo *et al.*, 2016). Saline and more alkaline soils should be avoided (Recha, 2017).

The piece of land ought to be completely ready with great dampness and the absence of enormous soil blocks and be of fine filth. Diggers, bulls and farm vehicles can be utilized for furrowing (Muindi, 2019b). Planting should be done at the beginning of downpours, after 30mm of precipitation is achieved if production is rain-dependent (Wambua *et al.*, 2019a).

Spatial planting is suggested to provide adequate space for plant growth such that there is no competition among the plants (Hochman *et al.*, 2020). When planting bulls are used to plough, seeds are placed along the edge of the trench (Boutchuen *et al.*, 2019). For the prevention of soil and seed-borne diseases and better yield, seeds ought to be treated with fungicides and insect poisons. Moreover, it is vital to routinely change the source of the seed (Jadon *et al.*, 2020). Seed rate shifts with the size of the seed and the season whereby between 22 to 26 kilograms per hectare or 8 to 15 kilograms per section of land (acre) or 4 to 8 'gorogoro' (tins) per hectare of land is suitable (Musyoka *et al.*, 2020). The profundity of establishing ought to be reserved at 3 to 5 centimeters. This distance might be expanded to 7.5 centimeters if the soils are dry to avoid scattered germination (Bhusara *et al.*, 2018). The spacing between columns ought to be 45 centimeters and amid plants 15 centimeters.

Germination takes place between 5-7 days and this varies depending on the varieties and natural variables (Karimi *et al.*, 2019). Green grams can be planted solitary or intercropped with different plants like cowpeas, sorghum and maize among others

(Wambua *et al.*, 2017). Green grams have a determinate development propensity, blossoms in 40-50 days and have potential yields going from 300-1500 kg per hectare (Suryavanshi *et al.*, 2019).

2.2 Characteristics of Green Gram Varieties

Green grams are broadly cultivated in Kenya. The varieties can either be improved or local (Bisht *et al.*, 2020). Green gram is ranked as a second-income generation agro-enterprise in semi-arid areas, it comes after indigenous chicken. The low productivity of green grams is mostly associated with a lack of improved varieties. Therefore, breeders have done some breeding to improve the productivity of green grams and have come up with several varieties of green grams including the following;

N22 variety which flourishes well in very well-drained sandy loamy soils. Their seeds are chromatic in color, tolerant to powdery mildew, yellow mosaic and aphids and is also semi-determinate plant. It matures between 80 to 90 days (Mulika *et al.*, 2019). The variety performs well in an altitude of between 500 to 1600m above sea level, precipitation of around 600mm yearly and temperatures of between 28-30^{0}C.

N26 variety which is commonly referred to as Nylon green grams has a determinate development and their cases become dark when mature containing glossy green grains. It matures between 60 to 65 days (Mulika *et al.*, 2019). This variety is drought resistant and therefore can be planted in semi-arid and well-watered areas of between 60 and 1600 altitude. Altitudes more than 1800m make the pods set poorly. It performs well in well-drained sandy loams. Since it matures early, it is planted in the drier areas of Tharaka Nithi, Mbeere, Kitui, Mwingi, Makueni and lower Machakos counties.

KS20 variety is commonly referred to as Uncle Green grams. Pods become earthy colored when dry containing dull green seeds which are greater in size contrasted with N26. They develop in about 80 to 90 days (Mulika *et al.*, 2019). It is tolerant to aphids, yellow mosaic and moderately resistant to powdery mildew. They require well-drained sandy and loamy soils for best performance and do not do well in waterlogged soils. It grows well in a warm humid climate of 25-35°C, 400-550mm of rainfall which should be well distributed throughout the growing period. They are propagated in Tharaka Nithi, Makueni, Machakos and Kitui. The variety can be grown at an altitude of 1600m above sea level. They are grown in Tharaka Nithi, Meru, Machakos, Baringo, Makueni and Kitui counties.

KAT 00309 is commonly referred to as Karembo green grams. It is tolerant to most of the diseases of green grams. It matures early between 65- 75 days and it is a high-yielding variety producing an average of 8-9 90-kilogram bags per acre. It has large brown pods containing green shiny grains. It does well in a warm humid climate of 25-350C, 400-550mm of rainfall which should be well distributed throughout the growing period. They require well-drained sandy and loamy soils for best performance and do not perform well in waterlogged soils (Mulika *et al.*, 2019). They are drought and heat-tolerant. They are propagated in Tharaka Nithi, Makueni, Machakos and Kitui counties.

KAT 00301 is commonly referred to as Ndengu Tosha green grams. It is an early maturing variety taking around 65-70 days to mature. It produces about 8-10 90-kg bags per acre because it is a high-yielding variety. The pods are green in color containing shiny green seeds. It is heat and drought-resistant. The variety does well in a wide range of climatic conditions. The best cultivation is done in well-drained loamy and sandy soils and doesn't develop well in water-logged soils (Mugo, 2021). They require precipitation of between 400-550mm and 25-35^{0}C. They are propagated in Tharaka Nithi, West Pokot, Isiolo, Machakos, Tana River and Baringo counties.

KAT 00308 variety is commonly referred to as Biashara green grams. It is early maturing, taking about 65-75 days. It produces high yields ranging between 8 to 9, 90 kg bags per acre. It is tolerant to aphids, and yellow mosaic and moderately tolerant to powdery mildew. The pods are cream in color and the seeds are large in size and shiny. They do well in semi-arid and well-watered areas. The variety doesn't perform well in waterlogged soils. It is tolerant to drought and heat. It is grown from sea level to 1600m above sea level, 25-35^{0}C of temperature and 400-550mm of rainfall which is well distributed. They can be planted in Tharaka Nithi, Taita Taveta, West Pokot, Baringo, Tana River, Machakos and Isiolo counties (Mugo, 2021).

2.3 Importance of Green grams farming in Tharaka North and Tharaka South Sub-counties

2.3.1 Income generation

Green grams are grown for income generation. A 90-kg sack can be sold at an average of Ksh. 8,100. Therefore, farming is a source of income for taking care of other bills like school fees among others (Nair and Schreinemachers, 2020).

2.3.2 Human Consumption

Green gram is a nutritious crop that is great in protein content, vitamins and even minerals making it an ideal supplement to a cereal-based diet which is vital in tackling malnutrition in protein calories (Musyoka *et al.*, 2020). When consumed it is a source of protein for individuals who can't bear the cost of meat protein or veggie lovers. 100 grams of green grams gives 7.6g of protein, a moderate sum that can help one meet the suggested everyday consumption which is 0.8g per kilogram of body weight (Mukhtar *et al.*, 2017). They are likewise a decent wellspring of lean protein which lacks fat (Kamboj and Nanda, 2018).

They are also low in calories and fat, giving simply 105kcal and 0.38g respectively per 100g of cooked (bubbled) mature green grams. This is because of their complex carbs and fiber which additionally makes them delay in the process of digestion. Accordingly, they discharge energy much more slowly expanding the sensation of totality. Hence, they are great for weight management.

Green grams also give moderate measures of dietary fiber of around 7.6 grams per 100g, which is vital for a healthy digestive system. It also increases the volume of the stool and extends transit time. The fiber likewise ties poisons and cholesterol and supports their expulsion from the body and consequently bringing down blood cholesterol levels which lessen the danger of cardiovascular infections (Ketha and Gudipati, 2018). Green grams are wealthy in folate, important during pregnancy, giving around 40%, that is 159 mg per 100g of the suggested day-by-day intake. It forestalls instances of neural tube problems, for example, spinal bifida and additionally guarantees ideal improvement of tissues and cells (Singh and Yadav, 2020).

Green grams, just like most legumes are great wellsprings of iron, a fundamental mineral that helps the body to move oxygen, enhance energy creation and digestion. The mineral is likewise critical to forestall the lack of iron sickliness and anemia, which is the most well-known supplement inadequacy in the world. To expand the accessibility of iron for retention, individuals are encouraged to consume iron-rich food sources, not simply green grams, but also other food varieties plentiful in Vitamin C which can be found in many fruits like citrus and leafy greens (Muindi, 2019c). They are also a source of different minerals like manganese, calcium, magnesium, phosphorus, potassium and zinc. Eating them can in this manner empower individuals to get their day-by-day portion of these minerals which are fundamental for the typical working of the body (Oghbaei and Prakash, 2017).

2.3.3 Animal Feeds and Bedding

Green gram straws are used as silage or hay for supplemental feeding in animals (Naz *et al.*, 2019). The animals that can benefit from green gram feeds include pigs and rabbits among others. The straws are rich in energy and protein content. The protein content is about 9-12% higher than that in other cereals used as supplemental feeds (Islam and Khan, 2021). They ensure that growth is maintained in animals. The husks of the plant are also used as animal beddings (James *et al.*, 2019).

2.3.4 Improving Soil Fertility

They are also used as green manure for improving soil fertility (Ansari *et al.*, 2022). They are grown before cultivation of the main crop and when about 50% of the plants have flowered, they are cut down and buried to decompose. Because of their ability to fix nitrogen, they end up improving soil fertility and thus improving the performance of main crops (Ansari *et al.*, 2022). This makes the farmers avoid the use of chemical fertilizers.

2.3.5 Cover Crop

Green grams grow rapidly thus providing a cover crop (Ansari *et al.*, 2022). This ability makes them prevent weed germination as they are sheltered by the green grams thus lacking sunlight which is necessary for any plant growth (Kaye and Quemada, 2017). This reduces the cost implications of weeding to the farmer. It also ensures that nutrient competition is reduced.

2.4 Challenges Affecting Green Grams Cultivation in the Field

2.4.1 Diseases

Green grams cultivation is encountered by several challenges among them being diseases, attack by insect pests such as flower thrips, aphids and white flies among others, drought and even agronomic practices which are poor (Machocho *et al.*, 2012). The most common diseases of green grams include powdery mildew which coats the surface of a leaf therefore lowering the ability of a leaf to absorb sunlight and consequently leading to reduced photosynthesis (Pratap *et al.*, 2019). This in turn lowers the plant nutrients and therefore leading to reduced growth and consequently poor yields in plants. The other common disease is yellow mosaic virus which leads to chlorosis of the leaves, whereby chlorophyll, responsible for trapping sunlight energy is lost and therefore the leaf can not photosynthesize any longer (Sandhu *et al.*, 1985). This also leads to stunted growth and a reduction in overall yield. Root rot is also a common disease in green grams, the roots rot and can not absorb water and mineral salts from the soil anymore resulting in stunted growth and decreased yields (Ochichi, 2015).

2.4.2 Drought

Drought is another great challenge encountered in green grams cultivation. It has several negative impacts on crop development and overall yield (Daryanto *et al.*, 2015). They include reduction in shoot and root growth, the leaf area becomes small in case of drought and therefore photosynthesis is also reduced, uptake of nutrients and translocation which is aided by water is also affected among others.

2.4.3 Poor Agronomic Practices

Poor agronomic practices that affect green gram productivity include poor soil management where soils are not checked for proper nutrients that help the green grams grow at optimum conditions (Latha *et al.*, 2018). Delays in weeding lead to stunted growth because weeds compete with plants for nutrients while untimely disease and pest management also contribute to losses attributed to damage to vegetative and reproductive parts (Swaminathan *et al.*, 2012).

2.5 Effects of Bugs on Green Gram Cultivation

Bugs are the most thriving creatures existing in each portion of nature (McGavin and Davranoglou, 2023). They are capable of feeding on different types of foods, have a high fertility rate, have a short lifespans and suspend development under unfriendly circumstances e.g. during winter (Oghbaei and Prakash, 2017). Crops are harmed by more than ten thousand types of bugs. The yearly loss caused by insect pests in the field is estimated to range from 15-100% globally (Mateos Fernández *et al.*, 2022). Different arthropod bugs influence green grams while growing on the farm and during storage. Bugs in the field incorporate, Root-knot nematodes, leaf diggers (*Lyriomyza spp*), aphids (*Aphis fabae*), cutworms (*Agrotis spp).*,flower thrips (*Megalurothrips sjostedti*), African bollworm (*Helicoverpa armigera*), Stink bug (*Coptosoma cribraria*), Pod bugs (Bean bug): (*Riptortus pedestri*), Grass blue butterfly (*Euchrysops cnejus*), whiteflies (*Bemicia tabaci*), red insect bugs (*Tetranychus sp.*), bean bruchids (*Acanthoscelides obtectus*) among others (Wambua *et al.*, 2017). Losses of about 30 to 100 percent are brought about by arthropod attacks and rodents.

2.5.1 Cutworm

Cutworms (*Agrotis sp.*) damage youthful seedlings which are expurgated near the ground. They appear as dark hatchlings in soil, close to the plant that has been cut (Joshi, 2020). The bug is minor, however, where the populace is high, it can cause major damage. The hatchlings can be chased away with straw blended in with insect poison and molasses and splashed inside the field, digging up to open caterpillars to hunters and parching by the sun, applying debris around the plant, use of neem-based organic insect sprays, for example, Nimbecidine at 20ml in 20 liters of water and use Lambda Cyhalothrin 25g/Kg based items, for example, Karate at 20g in 20 liters of water (Wanigasekara *et al.*, 2021).

2.5.2 Root Knot Nematodes

Root-knot nematode causes lesions on the root system of the root-knot infected plant framework to get knotty leading to a 'beard root'. The development of galls on the root framework is an essential side effect and contaminated plants are found in patches in the field (Min *et al.*, 2020). The root framework is decreased and the rootlets are extraordinarily harmed. Harmed roots are affected in their capacity of taking-up and movement of supplements and water (Miriam *et al.*, 2019). Thus, plants shrivel throughout the hot time of day, particularly under dry circumstances and are stunted in growth (Bali *et al.*, 2018). To control this insect, fields where vegetables have been developed already should be avoided. After the readiness of the seedbed, dirt should be discarded. Seedbeds should be exposed to the sun if possible, bio-fumigate crops from different families and use nematocidal mixtures to eliminate nematodes (Ahmad *et al.*, 2021). High degrees of natural matter like compost and manure in the soil should be kept and neem cake powder should be added to the soil. The rotation of green grams with sorghum, baby corn, onions, maize, millet, sweet corn, cassava, sesame, or Sudan grass among different plants should be practiced. A rotation framework known as "strong" is suggested for managing root-knot nematodes. Trap harvests like marigolds *(Tagetes spp.)* can also be used (Roberts, 2022). Biocontrols like the use of nematophagous fungi could also be used (Miriam *et al.*, 2019).

2.5.3 Flower Thrips

Flower thrips *(Megalurothrips sjostedti*) eat leaves as well as petioles creating minuscule openings encompassed by stained regions but mostly incline toward feeding on flowers that become brown, dried, or totally contorted and fall before maturity (Satyapriya *et al.*, 2017). Thrips likewise attack pollen prompting a decline in fertilization and setting of seeds, pods are few and distorted (Singh *et al.*, 2020). Ploughing and harrowing prior to planting diminishes resulting thrips assaults by getting rid of pupae in the soil. Conservation of the natural enemies including *Orius spp*. and *Anthocoris spp.* and predatory thrips is vital in their control (Reitz *et al.*, 2020). Spraying using biological pesticides, for example, spinosad when the pervasion is extreme can be practiced (Mouden *et al.*, 2017). Early identification of pests is significant, especially at the beginning of blossoming. The harvest can be sprayed with natural products like extracts of plants: garlic, pyrethrum, neem and rotenone among others (Reddy, 2020).

2.5.4 Aphids

Aphids swarm the young leaves making them curved and in extreme cases, crops wither and die. Discharge of honeydew prompts mold development. They also transmit viral diseases, cause shrinking, curving and death of youthful leaves (Routray *et al.*, 2020). Aphids can be controlled by planting early, routinely screening, obliterating and covering plagued plant materials, practicing rotation of crops, installing sticky snares, and applying yellow water (Panigrahi *et al.*, 2021). Splashing a foamy solution of about ten to fifteen tablespoons brimming with liquid soap fluid in 20 liters of water, and applying neem-based plant insect sprays, for example, Nimbecidine at 20 milliliters in 20 liters of water (Meena *et al.*, 2019).

2.5.5 Pod-borers

Pod-borers harm is predominant on leaves leading to their premature falling. Afterward, only the larva's head pushes into the pods and the remaining body hangs out (Madhurima *et al.*, 2017). They can be controlled by monitoring crops habitually because there is just a short period between incubating to penetrating pods or buds, using hands to pick and obliterate the caterpillars. Usage of biological pesticides, for example, neem or *Bacillus thurungiensis* (Bt) items normally give great eradication of the insect pests, if used on the young caterpillars before the invasion of the pods (Islam *et al.*, 2019). Examples of pod borers include spiny pod borer which causes falling of blossoms and young pods. More established pods have a brown-colored spot where a larva has penetrated. Hatchlings are greenish at first and become pink before pupation, with the presence of 5 dark spots on the prothorax (Gahukar and Reddy, 2018). Adults are brownish moths while prothorax is orange in shading and front wings have a white stripe along the foremost edge. There are various ways of controlling this pest including; deep furrowing within 2 to 3 years to dispose of the quiescent pupa is suggested, planting short-term varieties of green grams early, developing sorghum that is tall as a sidekick plant to fill in as natural perches for birds (Gahukar and Reddy, 2018). Additionally, gathering and annihilating hatchlings and adults and introducing pheromone traps can also be used as control. Natural enemies like *Phanerotoma sp., Tetrastichus sp., and P. hendecasisella. and Braconhebetor* should also be preserved and used in their control (Rathore *et al.*, 2018).

2.5.6 Pod-sucking Bugs

Pod-sucking bugs draw the sap out of seeds and pods and lead to different degrees of harm contingent upon the phase of development of seeds at the hour of assault. Infestation may lead to rot, pod mutation, untimely drying, wilting of seeds, germination capacity loss and creation of void buds (Indiati *et al.*, 2017).

Bugs can be handpicked consistently and killed, particularly during blooming and the formation of pods. Natural enemies like praying mantises and ants should be preserved because they are significant in killing or stopping bugs. Spraying neem items towards the beginning of the day when the young stages are uncovered to repulse bugs can also be practiced (Bayu *et al.*, 2021).

2.5.7 Red Spider mites

Red Spider mites *(Tetranychus spp.)* retard plant development, blossoming, length and the number of pods as well as the seed count per pod. Parasites harm might be serious, especially throughout the dry season (Olubayo, 2019). Planting close to plagued fields should be avoided and successive utilization of a wide range of pesticides should also be avoided especially pyrethroids as this might prompt insect bug episodes. Utilization of an upward water system or sprinkling plants with a solid fly of water to knock off parasites and also to obliterate their networks can be applied making certain to shower the leaves underneath. Nonetheless, this ought to be done during the early part of the day to permit the foliage to dry since foliage wetness for a long period provides a conducive environment for the advancement of fungal diseases (Nag *et al.*, 2020).

2.5.8 Whiteflies

Whiteflies *(Bemisia tabaci)* cause dark spots on pods that inadequately get loaded up with withered seeds. Larva and adults penetrate and draw sap from the leaves causing diminished plants and leaves yellowing and withering of the plant when the bug is present in many numbers. Honeydew is also produced, prompting the leaves and pods to develop sooty mold decreasing photosynthesis (Taggar and Gill, 2012a). These insects can be controlled by conserving regular adversaries and parasitoids, showering Neem-based natural insect poisons like Nimbecidine at 20ml in 20 liters of water. Practicing intercropping with onions and garlic can also control white flies (Singh *et al.*, 2019b).

2.5.9 Bean Bruchids

Bean bruchids *(Zabrotes subfasciatus, Acanthoscelides obtectus)* are little scarabs of about 3 to 5 mm, they are brown or grey to ruddy brown in shading. Pervaded green grams show little dull round openings on their surfaces. In the seed, whitish hatchlings or pupae are found (Singh and Boopathi, 2022). Egg development happens in the green grams for around one month before the rising of the adult. The hatchlings feast on the seeds obliterating them or decreasing their limit of germination. The grown-up rises out of the seeds both in the field and storage leaving little circular openings on the green gram seeds which increase with the intensity of invasion (Soumia *et al.*, 2021).To control this bug harvesting should be done ahead of schedule to stay away from pervasions in the field, burning off all rubbish like vegetable oil, for example, cottonseed or coconut oil, practicing sun-oriented green grams drying prior to storage, cleaning and spraying of the store using methyl bromide and avoiding storing recently reaped grains of green grams together with old ones (Alemayehu and Getu, 2017). Before storing, mix or treat stored seed with a combination of plant parts, that have a pesticidal effect (for example neem, lantana, pyrethrum among others). Seeds can also be coated with oil from neem seed oil at a pace of 5millilitre per kilogram (Fan *et al.*, 2017).

2.6 Methods of Controlling Insect Pests

The introduction, dissemination, and establishment of insect pests and other plant diseases into new geographic areas or regions where they are not already present are all prevented by the regulatory and administrative measures known as plant quarantines (Yamamura *et al.*, 2016). While quarantines don't immediately get rid of pests that are already there, they are extremely important in stopping the spread of pests and the entrance of new ones. This in return protects agriculture, conserves the environment and provides food security.

2.6.1 Eradication and Suppression

Insect pest control options include eradication and suppression programs, each with its objectives, methods, and results. These initiatives seek to lessen how much insect pests affect agriculture, ecosystems, and public health. The goal of eradication is the full annihilation of a particular insect pest population from a certain geographic region while the suppression objective is to control pest numbers to a point that they no longer pose a serious threat to the environment or the economy, while total eradication may not always be achieved (Liebhold and Kean, 2019).

2.6.2 Chemical Methods

Chemicals known as insecticides are created with the explicit purpose of eliminating or controlling insect pests (Wojciechowska *et al.*, 2016). They are among the most popular techniques for controlling insect pest populations in a variety of situations, including agriculture, public health, and others. Insecticides can efficiently lower pest populations, but they don't result in total eradication. It is an immediate pest control method however it leads to pest resistance against insecticides, harms beneficial organisms, poses human and environmental risks.

Chemical compounds used in pest control to attract, control, or observe insect pests are known as attractants and semiochemicals (Cai *et al.*, 2017). These tactics lower insect populations and limit damage, even if it does not normally utilized to eradicate pests. It is a targeted method of pest control however is costly and needs to be integrated with other pest control methods.

Insect growth regulators (IGRs), commonly referred to as growth inhibitors, are chemicals used in pest management to thwart the development and growth of insects. By interfering with the insect's life cycle (by affecting their hormonal or physiological processes), they offer a targeted and selective method of controlling pest numbers (Wang and Liu, 2016). It is a selective and long-lasting control however, it takes a long time to achieve control and also leads to pest resistance to the inhibitors.

Repellants are chemicals that are used in pest management to keep bugs away from certain regions or targets (Deletre *et al.*, 2016). Repellants can be a useful tool in integrated pest management (IPM) techniques to reduce pest damage and human-wildlife conflicts, even though they are not normally utilized to eradicate pests. They reduce insect pests however, they have a limited duration of effectiveness and have environmental implications.

Sterilants are used to control pest organisms by applying chemicals or treatments that make them sterile, essentially stopping their ability to reproduce (Enkerlin, 2021). Sterile Insect Technique (SIT) or Sterile Insect Release Method (SIRM) are two names for this strategy. Although sterilants are not normally utilized for pest eradication, they are used in a variety of applications to lower pest populations and manage insect pests.

It is a targeted method of pest control but it is costly and may create pests that are resistant to the chemicals.

2.6.3 Biological Methods

Microbial control is a biological control technique that involves the use of certain bacteria, viruses, fungi, and protozoan diseases with the goal of eliminating insect pests. To decrease or eradicate pest populations, this strategy employs pathogens that infect and kill pests naturally (Kumar *et al.*, 2019). Examples of microbial control agents include the bacterium entomopathogenic nematodes for soil-inhabiting pests, *Bacillus thuringiensis* (*Bt*) for controlling caterpillars and fungal pathogens like *Beauveria bassiana* for several insect pests. The method is usually useful in organic farming.

The protection and encouragement of natural enemies is an environmentally friendly and sustainable method of managing and potentially eradicating insect pests in agricultural and ecological systems. This tactic depends on the promotion and preservation of natural predators, parasitoids, and other organisms that naturally regulate pest populations (Snyder, 2019). It is environmentally friendly and cost-effective however it is time-consuming, needs knowledge and expertise and needs to be supplemented with other methods of pest control.

2.6.4 Genetic Methods

The Sterile Insect Technique (SIT), also known as the propagation and release of sterile insect pests, is a technique used to reduce or eliminate populations of particular insect pests. In this method, insects are mass-reared, radioactively sterilized, and then released into the pest population (Dyck *et al.*, 2021). When sterile insects mate with their wild counterparts, they generate non-viable progeny, which over time reduces the number of pests. This method is environmentally friendly and sustainable however it is costly and has non-target effects.

Genetically engineered or genetically modified plants are designed to have specific genes that provide resistance to insect pests (Anderson *et al.*, 2019). This method is a targeted control method and leads to increased yields however it has disadvantages such as impacts on the environment, differences in public perception and regulatory oversights.

2.6.5 Mechanical Methods

Hand destruction involves physically inspecting pests on plants before manually eliminating or killing them (Blanco *et al.*, 2016). This method is labor-intensive and only applicable to small-scale farming.

In different agricultural and pest control contexts, insect pests are captured and eliminated using traps (sticky traps, prehormone traps or light traps), suction devices(mechanical sunction systems and hand-held vacuums), and collection equipment (combine harvesters and vacuum harvesters) (Sorribas *et al.*, 2016). This method is of high precision, environment friendly and can be used for monitoring insect pests however it has limited efficacy, is costly and requires a lot of labor.

The crushing and grinding method involves physically grinding or crushing insects to kill them by use of hands or crushing devices (Dwivedi *et al.*, 2021). It is labour-intensive and can only be applicable to small-scale farming. However, the method has high precision and has an immediate action on the insects.

Exclusion by screens (greenhouse and screens insect screens) and barriers (physical barriers, tree bands and row covers) is a practical method of pest control that involves the use of physical barriers to prevent insect pests from entering specific areas, such as agricultural fields (Rechcigl and Rechcigl, 2016). This method is effective for pests that are quite large and mobile, such as crawling pests and flying insects. This method is environmentally friendly, selective and protects high-value crops however it is costly and limited to specific species of insect pests.

2.6.6 Cultural Methods

Crop rotation aims to sabotage the life cycle and reproduction of pest insects, making it more challenging for them to establish and develop (Francis and Clegg, 2020). This method is sustainable however, it is complex to plan and has limited control of insect pests.

By distracting or attracting pests away from the primary crop, trap crops are a management strategy used in agriculture to control and reduce insect pest populations. This strategy includes growing particular plants or crop kinds that are very alluring to pests as a means of diverting pests away from the main crop (Sarkar *et al.*, 2018). This method is cost effective and environmentally sustainable however it lacks specificity and needs effort to manage.

Crop residue management, commonly referred to as crop refuse destruction, is a farming technique used to control insect pest populations by removing the bugs' wintering and breeding grounds in the leftovers of harvested crops (Turmel *et al.*, 2015). Pests that deposit their eggs in agricultural residues respond well to this technique. It is sustainable however, it is less effective, has environmental implications, is costly and labor intensive.

A cultural practice and management technique used in agriculture to interrupt the life cycles of pest insects and lessen their effects is variation in the time of planting and harvesting crops (Rowen *et al.*, 2020). Although total insect eradication is not usually achieved with this technique, it can assist in decreasing pest numbers and harm. The method is sustainable however is influenced by weather and has limited effectiveness.

An efficient cultural technique for regulating and lowering pest populations in agriculture is the deployment of resistant crop cultivars (Dent and Binks, 2020). Although it might not result in the entire elimination of pests, it greatly reduces their negative effects on crops. Planting crop types with natural or genetically modified resistance to particular pests insects or diseases is part of this strategy. It has economic and environmental benefits however, varieties are resistant to specific insects and levels of resistance differ in different varieties. It is also costly and has limited availability.

2.6.7 Physical Methods

The heat method is a non-chemical approach also referred to as heat treatment or thermal pest control and is used to get rid of or manage insect pests in a variety of situations, such as agriculture. This technique focuses on increasing the temperature of the location of interest or product to a level that is fatal to the pest species while causing the least amount of harm to the surrounding area and structures (Rechcigl and Rechcigl, 2016). In this method the following important factors are in mind, Treatment Time: The time required for heat treatment might vary based on the type of pest, its stage in the life cycle, and target temperature. Some bugs may only need brief exposures, while others may need many hours of continuous heat to accomplish total elimination, Temperature Control: Attaining and holding the desired temperature for an adequate amount of time is necessary for heat treatment to be successful. Depending on the type of pest, a particular temperature between 120°F (49°C) and 140°F (60°C) is frequently needed because it can eliminate the majority of insect pests at all phases of development, Monitoring and Safety: During heat treatment, it's essential to keep an eye on the temperature and take safety precautions to avoid fires, damage to the things being heated, and danger to people or animals. Alarms and temperature sensors are frequently employed to keep things under control. This method is friendly to the environment, leaves minimal residues on the treated location and also can be used on a wide variety of insects. It is however not cost effective.

Cold treatment or cryogenic pest control is frequently used to describe the use of cold temperatures to eradicate insect pests. This method relies on freezing or even the use of lower temperatures on pests or infested objects to kill or immobilize insects in all of their developmental stages (Leopold, 2019). Temperatures and treatment duration should be controlled. This method is not cost-effective but it leaves minimal residues and is also friendly to the environment.

Applying various sources of energy can also be used to disrupt or eradicate pest populations. The forms of energy that can be used include; radiation, lasers and electric grids among others (Polajnar *et al.*, 2015). The effectiveness of this method depends on the insect pest targeted, the developmental stage and even environmental conditions. It works well when integrated with other methods of pest eradication.

Humidity is utilized to control insect pests that are sensitive to high humidity levels. This technique uses either high or low humidity levels to interfere with behavior, life cycle or the ability of pests to survive (Jena *et al.*, 2018). It works well when integrated with other methods of pest eradication but it is environmentally friendly.

Sound usage to get rid of insect pests in agricultural fields is a notion that has been researched to some extent, but its practical applicability as a solo pest control tool is restricted. Sound waves might influence insect pests by altering the communication and behavior that they exhibit (Polajnar *et al.*, 2015).This might be applied using acoustic devices, ultrasonic devices and acoustic traps. Insects may adapt to sound stimuli thus rendering the method ineffective with time.

2.6.8 Integrated Pest Management (IPM)

IPM is an all-encompassing strategy for controlling insect pests and other pests in agriculture. It combines a number of techniques such as biological management, cultural practices, adoption of crop resistant varieties and sparing pesticide application (Baker *et al.*, 2015). The objective is to use a variety of pest control techniques while lowering dependency on chemical pesticides to reduce hazards to the environment and human health. It is an effective method of pest control that ensures the preservation of beneficial organisms and minimal resistance development by insect pests. However, it is costly, labor intensive and if not effectively implemented it has the potential to damage crops (O'Reilly, 2020).

2.7 Effect of Climate Variability on Insect Pests

Insects are reliable indicators of the present climate change caused by humans. They have reacted to global warming in all manner anticipated, from phenology and distribution alterations to going through evolutionary changes (van Baaren and Candolin, 2018). Due to the significant direct impact of climate on their growth, reproduction and survival, insects are among the categories of organisms most likely to be impacted by climate change (Skendžić *et al.*, 2021). Insects may also adapt to climate change more quickly than long-lived creatures like plants and mammals because of their short generation periods and high rates of reproduction (Renner and Zohner, 2018).

2.8 Methods of Achieving Resistance

There are different ways in which a crop can achieve resistance. They include Tolerance, Antixenosis, and Antibiosis.

2.8.1 Tolerance

Infested plants can recover or even withstand the damage caused by insect pests compared to that of a susceptible plant that does not have this particular property. This occurs through the growth and compensatory characteristics of the plant by avoiding feedback inhibition and impairment of electron flow through photosystem II that is caused by feeding of the insects (Oloo *et al.*, 2020). Elevated levels of phytohormones are also crucial in providing plants with tolerance towards insects. This property does not interfere with insects' physiology or even behavior (Mangeni *et al.*, 2020).

2.8.2 Antixenosis (Non- preference)

Plants with this kind of resistance are non-preference of the insect pest by affecting their behavior. It involves a plant response and a pest response (Ughade *et al.*, 2018) concerning plant structural features that can be identified by vision and insect reactions that can be observed and measured. It is directed by multiple loci and their interactions (Nkhata *et al.*, 2019).

2.8.3 Antibiosis

This is a resistance whereby the biology of the pest is affected. Pest abundance and subsequent damage are minimized compared to that of a susceptible plant. This causes mortality or inhibition of growth, development, or even physiological processes in the insects. It is controlled by multiple loci and their interactions. It involves a plant defense response by producing inhibitory proteins, secondary metabolites and a pest response (Abdel-Banat and El-Shafie, 2021).

2.9 Characteristics of Green Grams that Contribute to Attraction and Resistance of Insect Pests

Leaf hairs release some terpenes which either repel or are toxic to insect pests (Tlak Gajger and Dar, 2021). The size of the leaves also influences insect resistance in that a large leaf can still remain with a large surface area for sunlight absorption to carry out photosynthesis when infested with pests compared to a leaf with a small area (Rubiales *et al.*, 2015). More succulent leaves also are able to attract pests compared to less succulent leaves. This is because, in succulent leaves, pests have more to feed. The duration a crop takes to mature determines whether a crop will evade insect attacks or it will not. Research shows that crops that mature earlier can evade pests as by the time the pests grow in population, harvesting should already been done (Mulwa *et al.*, 2023b).

2.10 Effect of Synthetic Substances used to Annihilate Bugs in the Environment

Insecticides play a significant role that has positively transformed the field of agriculture. Around 4.6 million types of pesticides are applied to the environment and insect sprays represent the biggest percentage of the pesticides used on the planet to expand the productivity of fiber and food (Campos *et al.*, 2019). Despite their significance, insect poisons likewise have adverse consequences including harmful impact on non-target organic entities, buildups in soil, water, air and food as well as resurgence and resistance of insect pests (Zhang *et al.*, 2018). Above 645 types of mites and insects have created resistance from insecticides with five hundred and forty-two types of arthropods impervious to somewhat around one chemical. Resistance of around 7,470 instances has been accounted for in bugs to a specific insecticide; 16 types of arthropods represented 3,237 (43 %) (Guo *et al.*, 2020). The impacts of insect poisons on man's well-being are more unsafe given their contact either indirectly or directly. Annually, over 26 million persons face the unfriendly impact of pesticide damage with almost 220,000 deaths. Large quantities of individuals are exposed to pesticides consistently, essentially through farming. Globally, around 36 % of laborers work in agribusiness, this number is ascending to practically 50 % in Southeast Asia and the Pacific and to 66 % in sub-Saharan Africa (Chrustek *et al.*, 2018). However, with every one of their risks, the development of insect sprays is constantly expanding in the global exchange. Worldwide pesticide utilization was estimated to be 3.5 million tonnes in the year 2020 (Sharma *et al.*, 2019). We are ceaselessly confronting the difficulties in diminishing the rate of insect pests and vectors to keep a protected climate for people in the future (Stehle *et al.*, 2018).

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study Area

The study took place in Tharaka North and Tharaka South Sub-counties, one study site was at Tharaka University farm at an altitude of 621 meters above sea level and the other study site was at Mukothima (Irunduni) at an altitude of 780 meters above sea level. The study sites are in Tharaka Nithi County which is sited in the eastern part of Kenya. The areas are recognized for farming, rural landscapes and cultural heritage although the land is degraded due to drought and diminutive ground cover (Gioto *et al.*, 2018). The vegetation in the regions is mainly acacia bushland containing little grass cover that favors browsers. Tharaka region has two rainfall patterns, which are low, unreliable and also poorly distributed that occur in March-May, long rains and in October- December, short rains.

The sub-county's precipitation ranges between 500-800 mm yearly and temperatures range between 24-37℃ although at times it can rise to 40℃. Mukothima and Tharaka University sites have different agroclimatic zones as elaborated by Kibetu (Kibetu, 2022). Mukothima is classified under agroclimatic zone 1 (ACZ1) and Tharaka University under agroclimatic zone 4 (ACZ4). The temperatures in Mukothima zones average between 21℃- 22℃ and an aridity index of between 0.30 and 0.45 while Tharaka University on the other hand has temperatures of between 22℃ -22.6℃ and an aridity index of 0.30- 0.55.

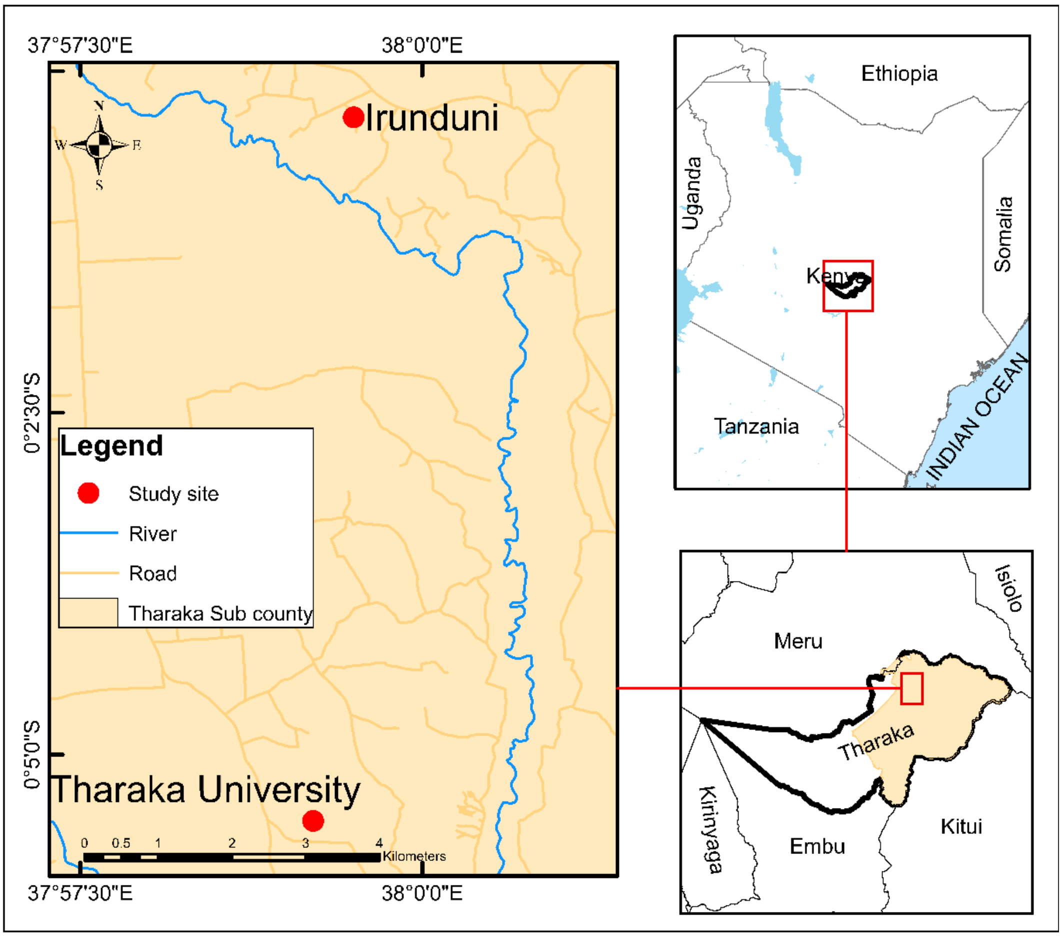

Figure 3.1: Map Representation of the Study Sites

3.2 Experimental Design

The experiment was laid out in a Randomized Complete Block Design (RCBD) with four replications (Figure 1). The varieties on each experimental were V_1 (KAT 00301 Variety), V_2 (KS20 Variety), V_3 (KAT 00308 Variety), V_4 (KAT 00309 Variety) and V_5 (N26 Variety) making a total of 20 treatments in each site. The plot sizes were 135 cm by 150 cm, the distance between plots and replications was both 1 meter. The control was the N26 variety since it is the commonly planted variety in the regions.

REPLICATION I				
V_4	V_2	V_5	V_1	V_3
REPLICATION 2				
V_3	V_2	V_5	V_4	V_1
REPLICATION 3				
V_5	V_3	V_4	V_1	V_2
REPLICATION 4				
V_1	V_3	V_2	V_4	V_5

Figure 3.2: Field Layout of Green gram Varieties as Laid out in Experimental Fields

Where;

V_1- KAT 00301 Variety (Ndengu Tosha)

V_2- KS20 Variety (Uncle)

V_3- KAT 00308 Variety (Ndengu Biashara)

V_4- KAT 00309 Variety (Ndengu Karembo)

V_5- N 26 Variety (Nylon-Control)

3.3 Preparation and Management of Experimental Field

According to Infonet Biodivision Farmer Communication Programme, 2019, the land was prepared by digging using a disc plough to make the tilth of the soil fine. Planting was done on the last week of March using certified seeds obtained from KALRO-Katumani whereby two seeds were dropped per hole at a depth of 4 centimeters using a panga. The spacing between columns was 45 centimeters and 15 centimeters amid plants which was achieved using a standard spacer.

The first weeding was done using a jembe during the second week of April, three weeks after seeds had emerged and a second weeding was done on the second week of May to prevent competition for nutrients. Harvesting was done when 95% of the pods had turned black for the N26, Karembo and Ndengu Tosha varieties and brown in Biashara and KS20 varieties by picking individual pods and putting them in different carrier bags during the first week of June. Different varieties from different blocks were threshed separately using a beating stick and the yield achieved was weighed using a standard weighing balance in Tharaka University Science Laboratory. Yields from the different varieties were then compared.

3.4 Data Collection

A field data sheet template was used in recording insect counts, leaves damaged and pods damaged twice per week. Ten plants from each variety were picked from each replication avoiding the plants on the edges because of field margin effects. Plant samples were randomly picked from each replication per the variety. The selection of one plant in a replication did not affect the selection of any other plant in the same replication.

3.4.1 Identification of Field Insects

Field insect determination was done using observation and the numbers of the insects were manually counted. Agronom-2005, PP yellow and blue coated fly insect sticky traps obtained from a local agrovet were set up at each treatment to trap insects (Kinyanjui *et al.*, 2021). The traps were then divided into portions of 5 by 5 cm on both sides of the traps and the insects were counted with the aid of a magnifying hand lens. For the aphids that could hardly be counted using naked eyes, they were scrapped off the pods and stems, preserved in 10% ethanol and carried to Tharaka University Science Laboratory the following day for counting using a dissecting microscope NTX-3C plus DCE-2 model (Muthomi *et al.*, 2017). The insects observed were compared with those in the EPPO Global Database (https://gd.eppo.int/photos/insecta) with the help of an entomologist for confirmatory tests for identification purposes.

3.4.2 Determination of Most Resistant Green Gram Variety

For each treatment, ten plants were sampled avoiding the border plants because of the field margin effects. In each plant, five leaves were selected randomly and the holes in those leaves counwere ted and recorded. The total number of leaves damaged in each plant was also recorded out of the overall number of leaves in that plant. The total number of damaged pods out of the overall pods in each plant was also recorded. During harvesting, the total number of pods harvested per plant were recorded and then after threshing, each treatment's yield was recorded. Resistance was moderated using the procedure proposed by Ogecha (Ogecha *et al.*, 2019).

Insect resistance according to the severity of leaf damage in five leaves per plant and the number of pods damaged per plant.

i. No damage and infestation
ii. Light damage and infestation 5% of plant parts damaged or infested by pest
iii. Average damage and infestation 5 and 50% plant parts damaged
iv. Considerable damage and infestation 50% plant parts damaged and severe stunting or wilting
v. Plants with very high infestation levels and severity of damage or wilted and dead plants

3.4.3 Investigating the Relationship between Insect Infestation and Yield

Harvesting was done manually per variety and yield in terms of kilograms was compared with the level of insect infestation and level of pods and leaves damage per variety to evaluate the relationship (Singh *et al.*, 2019b). Since the breeders for each variety according to the Green Grams Hand Book- SASOL Foundation, 2015, have already determined the expected yield per acre calculations per plot were determined and the variance from the expected yield was used to determine the relationship between the variety yield and insect infestation. At the end of the experiment, total yields were recorded for purposes of correlation analysis. Harvesting was done per block per variety, pods were then threshed separately using beating sticks and yields were determined using a weighing balance scale.

3.5 Data Analysis

The results were statistically expressed using mean and standard deviation to report on data precision. All parameters excluding yield were analyzed using Friedman's two-way nonparametric ANOVA procedure of SAS 9.2. Yield data was analyzed using a two-way analysis of variance using SAS 9.0 (2002). The mean separation was done using Tukey’s HSD (Tukey’s Honestly Significant Difference Test) at 5% significance. For the correlation, a non-parametric Spearman’s test was used.

3.6 Statistical Model

Statistical model for analyzing the levels of insect pest infestation and levels of insect pest resistance in different green gram varieties.

$Y_{ijk} = \mu + V_i + \beta_j + \varepsilon_{ijk}$

Where;

$\mathbf{Y_{ijk}}$ = dependent variables,

$\boldsymbol{\mu}$= overall mean,

$\mathbf{V_i}$ = Fixed effect due to i^{th} variety (i= Nylon, Uncle, Ndengu Biashara, Ndengu Tosha, Ndengu Karembo)

$\boldsymbol{B_J}$=Effect due to j^{th} block (j= Tharaka University and Mukothima site)

$\boldsymbol{\varepsilon_{ijk}}$= Random error

3.7 Ethical Considerations

Approval to carry out research was sought from the University ethics review committee before getting an introductory letter from the directorate of postgraduate of Tharaka University for purposes of getting a permit, clearance and authorization letter from NACOSTI. The study ensured that described procedures were done ethically to ensure fidelity and justice. Literature cited in this study was acknowledged to avoid the issue of plagiarism. Finally, the findings of this study will be shared with the local community and the policymakers for the benefit of all.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

4.1 Insect Pests Infesting Green Grams in Tharaka North and Tharaka South Sub-Counties

The variety of green grams with the highest mean number of white flies was Nylon (N26), followed by Biashara, Tosha, Karembo and Uncle (KS20) in that order. The mean number of white flies in N26, the highest (515.7), differed from the lowest recording variety KS20 (334.3) by an average value of 181.4 (<0.05). The same pattern of infestation was observed for aphids with Nylon (N26) recording the highest (468.8) mean number and Uncle (KS20) recording the lowest (323.9) (table 4.1). In general, N26 variety was the most susceptible to insect pest attacks while the KS20 was the least susceptible. The infestations by African pod suck borers and leaf weevils were also noted, although their mean values were low and not significantly different in all the studied varieties (<0.05).

Table 4. 1**:** Insect Types and Numbers in the Planted Green gram Varieties

	Varieties						P value	
Parameters	N26	KAREM	KS20	BIASH	TOSHA	SEM	Variety	Site
Whiteflies	515.7[a]	352.8[b]	334.3[b]	446.33[c]	420[c]	12.2	0.0001	0.0166
Aphids	468.8[a]	394.5[b]	323.9[c]	459.6[ad]	413.6[db]	12.08	<0.001	0.031
AFB	0.250	0.125	0.120	0.250	2.625	1.13	0.493	0.441
Leaf Weevil	1.00	0.875	2.50	2.50	1.750	0.71	0.327	0.0013

Means within a row with the different superscript letters are statistically different ($p < 0.05$).

White flies- *Bemisia tabaci,* Aphids- *Aphis craccivora*, African pod suck borer- *Riptortus pedestris* and Leaf weevil- *Otiorhynchus sulcatus*

AFB-African Pod Suck Borers, KAREM- Karembo BIASH- Biashara SEM- Standard Error of Means

Different types of insects were observed as indicated in table 4.1**.** There were significant differences in some of the insect pests (white flies and aphids) observed in different varieties but in some of the insect pests (African pod suck borers and leaf weevils), there were no significant differences. Insects observed in the sites were white flies, aphids, African pod suck borers and leaf weevils. All the four insect types observed in the study belong to different genetic families however, aphids, whiteflies and African pod suck borers damage the plants by sucking sap from various parts of the plants like the leaves, stems, flowers and even the pods. The leaf weevils have elongated snouts that pierce on the leaves causing irregularly shaped holes thus reducing the surface area for photosynthesis and reducing nutrient manufacturing in plants.

In research conducted in 16 different counties, Tharaka Nithi being one of the semi-arid counties represented, the number of aphids was recorded to be very severe and that of whiteflies being severe in green grams (Murage *et al*., 2020). Therefore, the findings of this study were in line with this research since it was noted that white flies and aphids caused the most significant damage to the planted green gram varieties. The results were also in line with those of Machocho who also observed white flies and aphids among other pests as major pests of economic importance when it comes to legume production, green grams being a legume (Machocho *et al*., 2012). The results also concurred with observations made in a study that recorded green grams infestation with pod borers, white flies and aphids in Katumani and Katangi study sites (Mulwa *et al.*, 2023). (Kamphuis *et al.*, 2013) also recorded that aphids are among the major sucking insect pests on legumes that are capable of causing big losses. This is because aphids have mechanisms of even evading pesticides used to eradicate them by detoxifying these chemicals. In addition, research studies in India, the ancestral origin of green grams also recorded the presence of white flies, pod borers and green jassids in the green grams plantations (Brishbhan and Bhowmick, 2016). This therefore proves that there is a need to produce legumes that are pest resistant.

Although some research studies conducted on beans in record more types of insect pests attacking green grams including many types of pod boring insects, green grams falling under the bean family, the types of insects in this study were lesser (four species) (Prakash and Rao, 2018). This could have been the effect of changing ecological zones and seasons since this determines the types of insect pests that attack crops (Altieri *et* *al.*, 2015).There were some insects like African pod borers and leaf weevils in Mukothima site that were not present in Tharaka University site. This concurs with the study that was carried out that records that the number and type of phytophagous insects like white flies in wetter or cooler parts being more and diverse than in the drier parts (Mudereri *et al.*, 2021). In this study, Tharaka University site is drier than Mukothima site. The lack of significant differences in African Pod borers and Leaf weevils in the different treatments of green grams signifies some form of resistance that could be attributed to the season and location of planting (Lu *et al.*, 2008). Different green gram varieties planted in this study showed differences in the number of insect pest infestations with N26 having the highest numbers and KS20 having the lowest.

Different varieties of green grams have different leaf hair densities which is one of the morphological traits they assessed that could cause variation in pest infestation of green grams in the field with KS20 having the highest and N26 having the lowest number of leaf hair densities (Mulwa *et al*., 2023a). Angle of inclination of trichomes, the size and the density also interact with the insects to determine how soybeans resist insects (do Valle *et al.*, 2012). Therefore, this explains the highest number of insect pests on N26 and lowest in KS20 since the density of leaf hairs is negatively related to insect pest infestation as explained by these two studies. The number of leaf hairs in plants is mostly genetically determined, although in some instances it is determined by the ecological conditions of the area of planting (Colicchio, 2017). Plants with trichomes have advantages over plants without trichomes in matters of herbivores and insect pest attacks because trichomes secrete terpenoids. Leaf hairs are some kind of trichomes thus this explains the reason why N26 had more numbers of insects in this study.

Another study recorded that trichomes are the first line of defense when it comes to plants. They release repellants and toxins, which are chemical in nature and terpenes which are volatile (Al-Khayri *et al.*, 2023). They provide resistance by either antixenosis in case of the repellants and by antibiosis in case of the toxicity. Therefore, N26 with less trichomes are mostly attacked by the insects compared with the KS20 variety which has the most number of leaf hairs and therefore able to repell the insects more. In addition N26 had the highest leaf moisture content, KS 20 has the least moisture content and the other three varieties were intermediate (Mulwa *et al.*, 2023).This could be presumably because N26 has the thickest lamina and KS20 the thinnest lamina among the planted varieties. A study conducted on black gram genotypes showed preference to whiteflies because of their high moisture content, could have been the same case for N26 variety was since it was the most preferred variety by insect pests because of its thicker lamina therefore being more succulent for feeding by the insects (Taggar *et al.,* 2012). Ndengu Biashara had no significant difference in the number of insect infestations with N26 probably because it also has lesser number of hair denstities (Mulwa *et al.,* 2023). The remaining two varieties Karembo and tosha were averagely infested by the insects because their leaf hair densities are moderate.

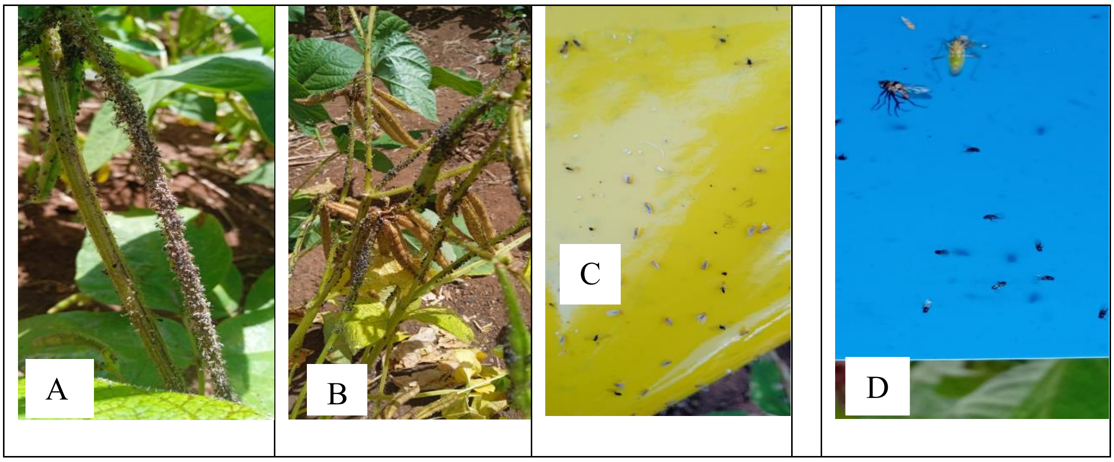

Figure 4. 1**:** A- Aphids and White flies on Stem B- Aphids and Whiteflies on Pods C- Aphids and White flies on Yellow Trap and D- Aphids and White flies on Blue Trap

(Source: Author, 2023)

Figure 4.1 A and B shows aphids and whiteflies on stems and pods respectively. As they coat the surfaces, they suck sap from them as they induce saliva which is toxic inside the plant. They also produce honey dew, which is sugary in nature and attracts other microorganisms which are pathogenic in nature. The microorganisms cause early plant senescence and aging of the plant. As they coat the surfaces too, they reduce the surface areas that are exposed to getting sunlight energy for the sake of photosynthesis (Mishra *et al.*, 2015). Photosynthesis is the manufacturing of food by the plants using carbon (iv) oxide and chlorophyll in presence of sunlight energy. Reduction in photosynthesis therefore makes the plants to lack essential nutrients that they need to grow and produce. In return, there is poor productivity in the crops as evidenced in the figures.

Figure 4.1 C and D respectively shows aphids and whiteflies trapped on sticky traps. The yellow trap has been designed to trap winged aphids, whiteflies and fungus gnats. However, the blue trap trapped the stray aphids and whiteflies because it has been designed to trap thrips (Otieno *et al.*, 2018).

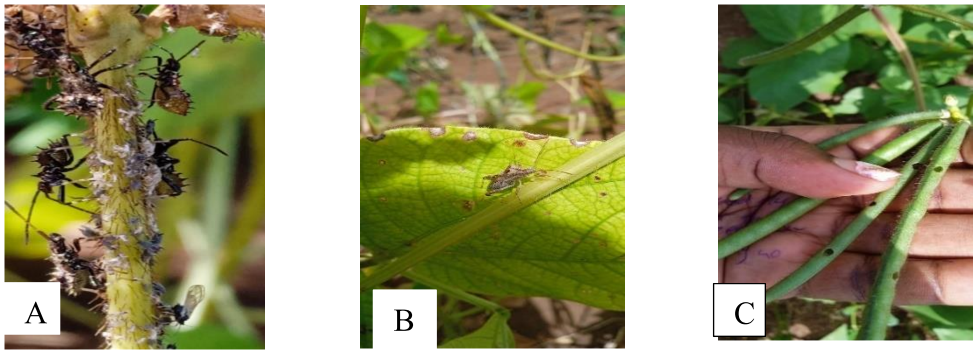

Figure 4 1**:** A- Pod Suck borers on Stem B- Pod Suck borers on Leaf C- Holes poked on Pods by Pod Borers

(Source: Author, 2023)

Figure 4.2 A and B shows african pod suck borers in various parts of the plants. Depending on the stage of growth of the seeds at the moment of attack by pod suckers, they suck sap from the pods and seeds and cause varying degrees of harm. Feeding might result in necrosis, abnormal pod development, early drying, shrinking of seeds, loss of germination potential, and the creation of empty pods (Arifunnahar *et al.*, 2019). Pod sucking bugs are challenging to manage since they often consume a variety of crops and are quite mobile (Rai *et al.*, 2014).

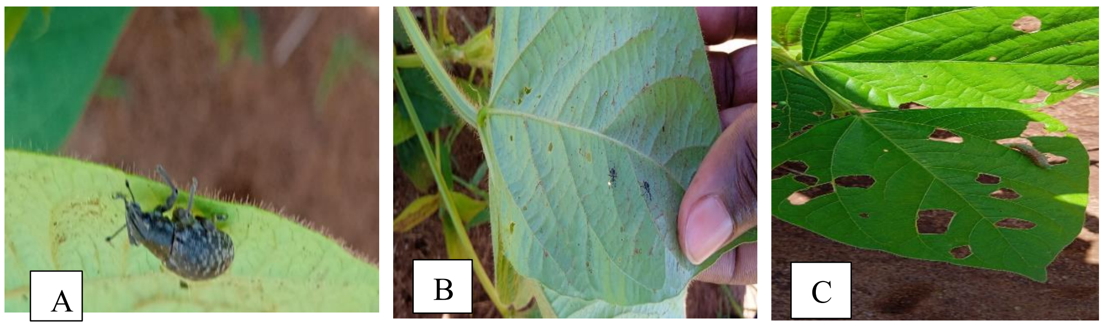

Figure 4 2**:** A- Leaf weevil B- Leaf weevil Poking Holes on Leaf C- Leaf with Poked Holes
(Source: Author, 2023)

Figure 4.3 shows the leaf weevils and the effect that the leaf weevils have on plants. They poke holes on the leaves and therefore reducing the surface area of photosynthesis and thus affecting the growth and development of the plant due to reduced photosynthates (Swaminathan *et al*., 2012).

Figure 4 3**:** Malformed Pods Due to Pest Infestation
(Source: Author, 2023)

Pod suckers cause malformed pods as illustrated by figure 4.4. This reduces the productivity potential of the pods as they cannot add the pods optimally. This was in line with a study that was recording insect pest complex of the year round country bean which noted that malformation of pods is one of the effects caused by pod sucking bugs causing reduced yields (Mollah *et al.*, 2017).

Table 4.2- Table 4.6 shows how white flies and aphids occurred in different sites. The yield for Mukothima site was low for all the varieties with Nylon variety scoring the highest yields (1065.51 Kg/ Hectare -Tharaka University and 805.77 Kg/ Hectare-Mukothima) in all the sites and ndengu tosha scoring the least yields (750.29 Kg/ Hectare- Tharaka University and 363.60 Kg/ Hectare - Mukothima) in all the sites. In Tosha variety the mean numbers of both whiteflies (4622.85) and aphids (17706.66) was high in Mukothima than Tharaka university site.

Table 4. 2: Mean Values of Insect Pests and Yields in Different Sites for Tosha

Site	Whiteflies	Aphids	Yields (Kg/Hectare)
TU	2596.30	771.51	750.29
MUKOTHIMA	4622.85	17706.66	363.60

Nylon variety had high number of whiteflies (2201.63) in Tharaka university site and high number of aphids (1797.14) in Mukothima site.

Table 4. 3: Mean Values of Insect Pests and Yields in Different Sites for Nylon

Site	Whiteflies	Aphids	Yields (Kg/Hectare)
TU	2201.63	721.59	1065.51
MUKOTHIMA	1730.47	1797.14	805.77

Uncle variety had high number of whiteflies (1706.099) in Tharaka university site and high number of aphids (1928.92) in Mukothima site.

Table 4.4: Mean Values of Insect Pests and Yields in Different Sites for Uncle

Site	Whiteflies	Aphids	Yields (Kg/Hectare)
TU	1706.099	573.75	965.38
MUKOTHIMA	1446.66	1928.92	597.5

Karembo variety had a high number of whiteflies (2397.36) in Tharaka University site and a high number of aphids (1550.95) in Mukothima site.

Table 4.5: Mean Values of Insect Pests and Yields in Different Sites for Karembo

Site	Whiteflies	Aphids	Yields (Kg/Hectare)
TU	2397.36	989.53	1006.83
MUKOTHIMA	1442.85	1550.95	781.75

Biashara variety had a high number of whiteflies (2397.36) in Tharaka University site and a high number of aphids (1550.95) in Mukothima site.

Table 4.6**:** Mean Values of Insect Pests and Yields in Different Sites for Biashara

Site	Whiteflies	Aphids	Yields (Kg/Hectare)
TU	2397.36	989.53	1006.83
MUKOTHIMA	1442.85	1550.95	781.75

The incidence rate of the insect pests being different in the different sites could be attributed to locational differences and biodiversity differences (Sharma *et al*., 2015). From the study Mukothima site had more incidence of aphids while Tharaka University site had more incidence of whiteflies and the thus Mukothima site had lesser yields. Aphids cause a higher percentage of losses compared to whiteflies which is attributed to their rapid reproduction rate and their capability to convey an extensive range of plant viruses compared to whiteflies (Muzira, 2015).

4.2 Determination of Resistant Green Gram Variety

Ndengu Tosha has the highest (2564.76 damage index) severity of leaves damaged which differed by 573.76 from N26 variety that had the lowest damage index of 1991.0. In addition, Ndengu Tosha had the highest number of holes of 4.45 and differed from N26 by 1.34. Nylon (N26) had the highest number of pods harvested with a value of 22.9 while KS20 had the lowest value harvested of 18.8.

Table 4.7**:** Incidence of Pods Damage and Severity of Leaves Damage

	Varieties						P value	
Parameters	BIASH	KAREM	KS20	N26	TOSHA	SEM	Variety	Site
No. of pods	20.4^{ab}	22.0^{b}	18.8^{a}	22.9^{b}	22.3^{b}	0.75	<0.001	<0.001
Incidence rate for pods	0.546^{a}	0.590^{b}	0.380^{c}	0.328^{cd}	0.599^{ab}	0.11	<0.001	<0.001
S.L damage	2275.6^{a}	2245.17^{a}	2029.8^{b}	1991.0^{c}	2564.76^{d}	23.2	<0.001	<0.001
No of holes	3.33^{ad}	4.08^{c}	3.52^{d}	3.11^{e}	4.45^{b}	10.8	<0.001	<0.001

Means within a row with the different superscript letters are statistically different ($p < 0.05$)

AFB-African Pod Suck Borers, KAREM- Karembo, BIASH- Biashara

S.L-Severity of leaf damage

SEM-Standard Error of Means

In this study, different green gram varieties showed different levels of insect pest resistance or susceptibility. Green grams have different morphological characteristics that influence pest infestation among the different varieties (Mulwa *et al.*, 2023). These morphological characteristics include but not limited to hair density of the leaf, leaf area, moisture content of the leaf, thickness of the wall of the pod and the time the plant takes to add branches, flowers and reach maturity. This is in line with the study as these morphological characteristics are the ones that explained how some varieties were able to achieve different levels of resistance. They confer resistance using different mechanisms either by tolerance, antixenosis or antibiosis (Sulistyo and Inayati, 2016).

From the study, N26 was not significantly different ($p < 0.05$). from Biashara in terms of insect pest infestation, they had the highest mean numbers (whiteflies- 515.7 and aphids- 468.8) of insect infestation because of the less hair density (Mulwa *et al.*, 2023). However, in the study, the incidence of pods damaged and severity of leaves damage N26 has the least. This signifies that there could be some resistance in the N26 variety because although it had the highest number of insect pests, it was the least damaged among the planted varieties. This resistance could have been achieved through tolerance because although insect infestation in Biashara and N26 variety was not significantly different, N26 performed better and produced higher yields than Biashara.

Tolerance, as exhibited by N26 in this study, is resistance where plants are able to withstand damage or even recover from damage by insects (Sulistyo and Inayati, 2016). This could have happened by photosynthetic compensation since the N26 variety has many numbers of leaves and also a large leaf area compared to other varieties planted in the study. Tolerance could also have been achieved through compensatory growth (CG) where a plant simply shows a positive shift in growth rate due to disturbance, utilizing the stored food for growth or even phonological delays where a plant delays phases of development due to disruptions (Sulistyo and Inayati, 2016). Ndengu Tosha on the other hand had the highest numbers of severity of leaves damaged and incidences of pod damage although it had a moderate number of insect infestations. This signifies that there could have been no resistance in the variety. Ndengu Tosha and the other newly released varieties have small leaf areas and lesser pod wall thickness and that could have contributed to the lowest levels of resistance (Mulwa *et al*., 2023). Although the study also records that early maturing varieties have chances of evading insect pests before they have multiplied, the duration of maturity of N26 is between 60 to 65 days and that of Ndengu Tosha is between 60 to 70 days, so they don't have a significant difference in terms of maturity. In addition, the study also records that N26 photosynthesizes more than Ndengu Tosha due to the large canopy of leaves and large size of leaves. Increasing photosynthesis in plants may solve the crisis of lack of food in the world because it increases the yield of the crops as evidenced by N26 variety in this study (Tadele, 2017). The yields increase could probably be attributed to this aspect. In as much as Ndengu Tosha is the most severely damaged in the leaves and the pods, there is no significant difference (p <0.05) between the damages of the three newly released varieties. This shows that they could be more morphologically similar in the leaves and pod structure.

The yield of N26 was not significantly different (p <0.05) from that of Karembo although Karembo had a moderate number of insects (whiteflies- 352.8 and aphids- 394.5) and therefore moderate damage of leaves signifying some kind of resistance. This resistance could have been achieved through antixenosis or antibiosis. Antixenosis is whereby a plant is not preferred by insect pests for feeding and antibiosis is whereby when the insect pests feed on the plants, their biology is affected. Karembo variety has the second highest number in leaf hair density after KS20 (Mulwa *et al*., 2023). Therefore, the leaf secretes terpenes which induce resistance in plants containing them. The terpenes release repellants and toxins, which are chemical in nature and terpenes which are volatile. They provide resistance by either antixenosis in case of the repellants and by antibiosis in case of the toxicity (Sulistyo and Inayati, 2016).

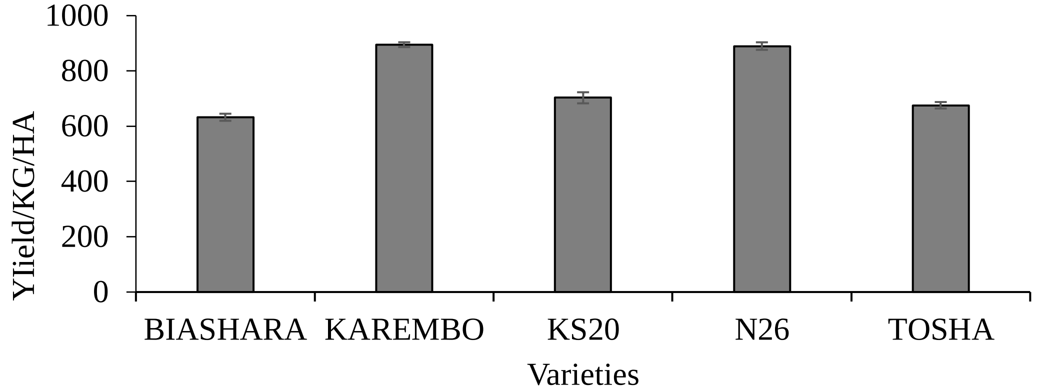

Figure 4. 2**:** Yields of Different Green Gram Varieties

In another study, N26 had the lowest yields compared to Ndengu Tosha, Karembo and Biashara (Muriithi, 2020). However, in this study, N26 produced the highest number of yields in this study probably because of its ability to resist insect pests. Other studies done concurred with these results that N26 had the highest yields (Mulwa *et al.,* (2023).

4.3 Co-relation between Yields of Different Varieties and Levels of Insect Pest Infestation

The relationship between yields and insect pest infestations was carried out using a non-parametric spearman's test. The results of different varieties are represented in Table 4.3 – 4.7. Table 4.3 whiteflies showed no significant difference with the pod damage. Aphids showed a negative relationship (-0.576) with pod damage and a positive relationship (0.527) with whiteflies. The severity of pod damage had a positive relationship (0.896) with pod damage, with whiteflies (0.039) and with aphids (0.453). The yield had a negative relationship with all the parameters, (-0.534) with pod damage, (-0.3935) with aphids and (-0.431) with the severity of pod damage. There was no significant difference between yields and white flies.

Table 4.8**:** Correlation between Infestation and Yield in Karembo

Parameters	Pod Damage	Whiteflies	Aphids	Severity of pod damage	YIELD
Pod Damage	-	-0.015^{ns}	0.576***	0.896***	-0.534***
Whiteflies		-	0.527***	0.039^{ns}	-0.089^{ns}
Aphids			-	0.453***	-0.3935***
Severity of pod damage				-	-0.431***
YIELD					-

*** <0.001, ** <.05, NS not significant, Yield-Kg/Hectare

Table 4.8 whiteflies showed no significance with the pod damage. Aphids showed a negative relationship(-0.409) with pod damage and a positive relationship (0.5623) with whiteflies. The severity of pod damage had positive relationship (0.947) with pod damage, with whiteflies (0.0085) and with aphids (0.365). Yield had a negative relationship with all the parameters, (-0.552) with pod damage, (-0.525) with aphids and (-0.5723) with severity of pod damage. There was no significant difference between yields and white flies.

Table 4.9**:** Correlation between Infestation and Yield in KS20

Parameters	Pod Damage	Whiteflies	Aphids	Severity of pod damage	YIELD
Pod Damage	-	-0.018^{ns}	0.409***	0.947***	-0.552***
Whiteflies		-	0.5623***	0.0085^{ns}	-0.116**
Aphids			-	0.365***	- 0.525***
Severity of pod damage				-	-0.5723***
YIELD					-

*** <0.001, ** <.05, NS not significant, Yield-Kg/Hectare

Table 4.9 white flies had a positive relationship (0.342) with the pod damage. Aphids showed a negative relationship (-0.551) with pod damage and a positive relationship (0.2004) with whiteflies. The severity of pod damage had a positive relationship (0.899) with pod damage, with whiteflies (0.3264) and with aphids (0.498). The yield had negative relationship with all the parameters, (-0.4088) with pod damage, (-0.249) with white flies, (-0.2033) aphids and (-0.3612) with severity of pod damage.

Table 4.10**:** Correlation between Infestation and Yield in Biashara

Parameters	Pod Damage	Whiteflies	Aphids	Severity of pod damage	YIELD
Pod Damage	-	0.342***	-0.551***	0.899***	-0.4088***
Whiteflies		-	0.2004***	0.3264***	0.249***
Aphids			-	0.498***	-0.2033***
Severity of pod damage				-	-0.3612***
YIELD					-

*** <0.001, ** <.05, NS not significant, Yield-Kg/Hectare

Table 4.10 white flies had no significant difference with the pod damage. Aphids showed a positive relationship (-0.307) with pod damage and a positive relationship (0.323) with whiteflies. The severity of pod damage had a positive relationship (0.9307) with pod damage, with whiteflies (0.052) and with aphids (0.276). The yield had a negative relationship with all the parameters, (-0.0272) with pod damage, (-0.7914) with white flies, (-0.375) aphids and (-0.267) with severity of pod damage.

Table 4.11: Correlation between Infestation and Yield in N26

Parameters	Pod Damage	White flies	Aphids	Severity of pod damage	YIELD
Pod Damage	-	0.0581^{ns}	-0.307***	0.9307***	-0.272***
Whiteflies		-	0.323***	0.052^{ns}	-0.7914***
Aphids			-	0.276***	0.375***
Severity of pod damage				-	-0.267***
YIELD					-

*** <0.001, ** <.05, NS not significant, Yield-Kg/Hectare

Table 4.11 white flies had positive significance (0.290) with the pod damage. Aphids showed a negative relationship (-0.321) with pod damage and a positive relationship (0.436) with whiteflies. The severity of pod damage had a positive relationship (0.907) with pod damage, with whiteflies (0.2972) and with aphids (0.3240). The yield had a negative relationship with all the parameters, (-0.739) with pod damage, (-0.407) with white flies, (-0.297) with aphids and (-0.756) with severity of pod damage.

Table 4.12**:** Correlation between Infestation and Yield in Ndengu Tosha

Parameters	Pod Damage	Whiteflies	Aphids	Severity of pod damage	YIELD
Pod Damage	-	0.290***	0.321***	0.907***	-0.739***
Whiteflies		-	0.436***	0.2972***	-0.407***
Aphids			-	0.3240***	-0.297***
Severity of pod damage				-	-0.756***
YIELD					-

*** <0.001, ** <.05, NS not significant, Yield-Kg/Hectare

Different varieties' yields were affected by aphids and whiteflies at different levels, as the number of insect pests increased in number, the yield decreased in number. Whiteflies and aphids caused significant damage to the different varieties planted. The damages which included leaf and pod damage consequently contributed to the overall yields that were achieved. Another study also identified white flies and aphids among other insect pests as some of the sap feeders that cause significant damage to the vegetative and reproductive parts of the green grams (Swaminathan *et al.,* 2012). This study shows that increase in the number of whiteflies and aphids caused a decline in the yields. This was in line with the study carried out on field pest infestation in green grams in Katumani that also showed a linear relationship with yield loss (Mulwa *et al*., 2023).

Karembo and KS20 green gram varieties' decline in yields was as a result of aphids which caused a significant effect of 0.3935 and 0.525 respectively with whiteflies causing insignificant effects. Biashara variety yields were affected by whiteflies which caused a significant effect on yield of 0.2033. Ndengu Tosha yields declined because of both whiteflies and aphids which caused significant declines of 0.407 and 0.297 respectively. None of the insect pests recorded in nylon variety caused a decline in yields. This shows that the variety was able to resist insect pests through tolerance because from the study it recorded the highest mean numbers of both whiteflies (515.7) and aphids (468.8). Therefore, most varieties' yields declined because of aphids. Nylon variety has large size of leaves which could have been preferred more by insects than the pods because they are also more succulent (Taggar and Gill, 2012b).

Decline in yield could be attributed to aphids due to several reasons; they incorporate saliva which is toxic in the plants thus making the plants not to grow in the manner that it is expected to grow under normal circumstances, they also have some secretions which coat the leaves and the pods thus limiting photosynthesis by lowering the surface area of the parts which are supposed to receive light energy for this process thus there is reduced nutrients in the growing plant (Makila *et al.*, 2018). Aphids feeding directly on the pods of plants and thus causing damage to pods according to a study that researched on the effects that aphids have on the green grams and the injuries that they consequently cause (Valenzuela and Hoffmann, 2015). The decrease in yields in some varieties is possibly attributed to white flies because they extract sap from leaves leaving a coating that blocks the leaves from carrying out photosynthesis efficiently thus the growing lacks enough nutrients (Taggar and Singh, 2020). In all the varieties, an increase in the number of whiteflies led to an increase in a number of aphids. This could be attributed to favorable climatic and ecological conditions since there is no record of a symbiotic relationship between the pests. Aphids had a weak positive relationship with the severity of pod damage. The higher the number of aphids, the higher the severity of the pod damage index. Whiteflies had the highest negative relationship with the yield. However, they had no significant effect on the pod damage which could probably be attributed to resistance since N26 has average pod wall hardness (Mulwa *et al*., 2023). Therefore, the yield could have been affected by reducing the rate of photosynthesis of the plants. The severity of pod damage and pod damage had a weak negative relationship with the yield. This means that the level at which the pods were damaged has little contribution to the yield of this variety.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

Green grams cultivation is often faced with several challenges in Tharaka North and Tharaka South Sub-counties. Among the major challenges is the challenge of insect pest attacks (Kilimo Trust, 2017). They can cause huge losses depending on the types of insects and also the population of the insects attacking them. Therefore, green gram varieties that have the ability to resist insects can reduce these losses caused by insect pests (Sharma *et al.*, 2010). Although varieties have been released that would probably counter this problem by maturing early, still this challenge has not been properly addressed and a study to compare the degree of pest resistance in the old varieties and the newly released varieties is very scanty.

The objectives were achieved through a field study and the hypotheses tested using Friedman's two-way nonparametric ANOVA analysis other than yield data which was tested using a two-way analysis of variance using SAS 9.0 (2002). Relationship between the overall yield and insect pest infestation was determined using non-parametric spearman’s test. From the results which have been presented in Chapter 4 insect pest resistance is possessed in some of the green gram varieties planted. This resistance has been made possible by physical characteristics in some varieties of which in the varieties which do not possess the characteristics, they are found not to be resistant.

5.1.1 Identifying Field Insect Pests

Insect pests cause 50-90% of crop yield loses in legumes (Kilimo Trust, 2017). Hence, identifying the insect pests causing major loses in green grams can form a vital tool in generating insect resistant green gram varieties against the identified pests of economic importance. This objective therefore, identified the insect pests causing significant loses in different green gram varieties.

Whiteflies and aphids were the insect pests identified in significant numbers and in significant differences among different green gram varieties. They are therefore capable of causing significant losses in green grams. The number of white flies in N26 was the highest with the value of 514.7 which differed by 180.4 from KS 20 which had a value of 334.3. The number of Aphids trapped in N26 was the highest with the value of 468.8 which differed by 144.9 from KS 20 which had a value of 323.9. This therefore, implies that the physical characteristics of N26 variety are able to most attract insect pests and KS20's physical characteristics least attract insect pests among the planted varieties.

5.1.2 Determining Resistant Green Gram Variety

Specific physical characteristics in different varieties of green grams conferred different abilities of resistance towards insects. These characteristics included sizes of the leaves, the densities of leaf hairs, the water content of the leaves and the hardness of the pods and leaves as recorded in previous studies. From the study, N26 was the most resistance as it had most numbers of leaves and the largest leaf area (Mulwa *et al.,* 2023). This kind of resistance could be regarded as tolerance as N26 was the variety with the greatest number of insects among planted varieties. Ndengu Tosha on the other hand was the least resistance variety because although it had moderate numbers of insect pests, the area of the leaves is small ($39 \pm 0.7cm^2$) and the pod wall thickness is the less (Mulwa *et al.,* 2023).

5.1.3 Effects of Insect Pests' Infestation on Green grams Development and Overall Yield

The number of white flies and aphids had negative relationships with the yield. As the number of insect pests increased so did the damage of the pods or the severity of pod damage which consequently led to decrease in yields in each variety planted. Therefore, insect pests cause decrease in the yields achieved in green grams.

5.2 Conclusion

The present study aimed at identifying the most pest resistant green gram genotype. White flies and aphids were identified as the most prevalent insect pests in green gram production in Tharaka North and Tharaka South Sub-counties in the March- May season (Whiteflies-Uncle-334.3, Biashara-446.33, Karembo-352.8, Tosha- 420, Nylon-515.7; Aphids- Uncle-323.9, Biashara-459.6, Karembo-394.5, Tosha- 413.6, Nylon-468.8). These insects attack the plants in their vegetative and reproductive parts. Therefore, they can cause a significant loss in green grams in all the five selected varieties hence affecting the economic value of the green grams and the nutrition of the residents of Tharaka Sub- County. Leaf weevils and African pod borers are also present in green grams during this growing season.

N26 green gram variety was the most resistant variety among the varieties planted, it had the least severity of leaves damaged and incidence of leaf damaged although it had the highest pest population. Ndengu Tosha on the other hand had the least resistance, it had the highest index of severity of leaves damaged and incidence of pods damaged. Correlation studies showed that insect pests had an effect on green grams development and the overall yield. They caused damage to the leaves and caused pods malformations thus affecting the yield. The yields anticipated by the breeders of the varieties was far from being achieved.

5.3 Recommendation

The following are the general recommendations to farmers and researchers and also for future studies:

i. Nylon (N26) green gram variety should be planted because it is the variety which had resistance to insect pests.
ii. Breeding for insect resistance in green grams should be done because although N26 is the most resistant variety, it achieves resistance through tolerance. Antibiosis is the best method of achieving resistance.
iii. Carry out research in October-December (OND) season to check whether there are varying types of insects in the season.
iv. Carry out research on large piece of land to check whether the results are in tandem.

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APPENDICES

Appendix 1: Nacosti Permit

REPUBLIC OF KENYA

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Ref No: 72386

Date of Issue: 13/August/2023

RESEARCH LICENSE

This is to Certify that Miss.. PURITY MUSYOKI WANJIRA of Tharaka University, has been licensed to conduct research as per the provision of the Science, Technology and Innovation Act, 2013 (Rev.2014) in Tharaka-Nithi on the topic: EVALUATION OF SELECTED GREENGRAM (Vigna radiata) VARIETIES AGAINST INSECT PESTS INFESTATION IN THE FIELD, THARAKA SUB-COUNTY, KENYA for the period ending : 13/August/2024.

License No: NACOSTI/P/23/28445

721386

Applicant Identification Number

Director General

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY & INNOVATION

Verification QR Code

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Appendix 2: Ethical Clearance

CHUKA UNIVERSITY

Knowledge is Wealth *(Sapientia divitia est)* Akili ni Mali

CHUKA UNIVERSITY INSTITUTIONAL ETHICS REVIEW COMMITTEE

Telephones: 020-2310512/18 P. O. Box 109-60400, Chuka
Direct Line: 0772894438 Email: info@chuka.ac.ke, Website: www.chuka.ac.ke

14th July, 2023

REF: CUIERC/ NACOSTI/403
TO: **Purity Wanjira Musyoki**

RE: Evaluation of Selected Green Gram (*Vigna Radiata*) Varieties Against Insect Pest Infestation in the Field, Tharaka Sub county, Kenya

This is to inform you that *Chuka University IERC* has reviewed and approved your above research proposal. Your application approval number is *NACOSTI/NBC/AC-0812.* The approval period is 14th July, 2023 – 14th July, 2024.

This approval is subject to compliance with the following requirements;

i. Only approved documents including (informed consents, study instruments, MTA) will be used
ii. All changes including (amendments, deviations, and violations) are submitted for review and approval by *Chuka University IERC.*
iii. Death and life threatening problems and serious adverse events or unexpected adverse events whether related or unrelated to the study must be reported to *Chuka University IERC* within 72 hours of notification
iv. Any changes, anticipated or otherwise that may increase the risks or affected safety or welfare of study participants and others or affect the integrity of the research must be reported to *Chuka University IERC* within 72 hours
v. Clearance for export of biological specimens must be obtained from relevant institutions.
vi. Submission of a request for renewal of approval at least 60 days prior to expiry of the approval period. Attach a comprehensive progress report to support the renewal.
vii. Submission of an executive summary report within 90 days upon completion of the study to *Chuka University IERC.*

Prior to commencing your study, you will be expected to obtain a research license from National Commission for Science, Technology and Innovation (NACOSTI) https://oris.nacosti.go.ke and also obtain other clearances needed.

Yours sincerely

Dr. Benjamin Kanga
SECRETARY

Chuka University is....... ...Inspiring Environmental Sustainability for Better Life

Appendix 3: Introductory letter

P.O BOX 193-60215,
MARIMANTI, KENYA

Education for Freedom

Telephone: +(254)-0202008549
Website: https://tharaka.ac.ke
Social Media: tharakauni
Email: info@tharaka.ac.ke

OFFICE OF THE DIRECTOR
BOARD OF POSTGRADUATE STUDIES

REF: TUN/BPGS/PL/: SMT15/03133/20 **25th July, 2023**

To Whom It May Concern,

Dear Sir/Madam,

RE: INTRODUCTORY LETTER FOR PURITY WANJIRA MUSYOKI, ADMISSION NUMBER: SMT15/03133/20

The above named is our postgraduate student undertaking a Master of Science degree programme in **Botany Genetics**. The student has finished coursework and is expected to collect data. The title of the research is ***"Evaluation of Selected Green Gram (Vigna Radiata) Varieties Against Insect Pest Infestation in The Field, Tharaka Subcounty Kenya."*** The study will be conducted in **Tharaka Nithi County.**

The candidate has defended the proposal successfully at the Faculty and has submitted the required number of corrected copies to the Office of the Director, Board of Postgraduate Studies. The candidate is expected to begin collecting data, analyse and write a report on the findings. The study is expected to be completed by March, 2024.

Any assistance accorded to him will be highly appreciated.

Thank you in advance.

Yours faithfully,

THARAKA UNIVERSITY
25 JUL 2023
DIRECTOR
P.O. Box 193-60215, MARIMANTI

Dr. Denis Obote, Ph.D.
Director,
Board of Postgraduate Studies.