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TITLE: ASSESSMENT OF NODULATION POTENTIAL IN MUNGBEAN (*Vigna radiata)* GENOTYPES.

NAME OF STUDENT: PASCHAL, LEONARD LENDA

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NAME OF SUPERVISOR: DR. BEATRICE MWAIPOPO

A RESEARCH PROJECT REPORT SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF BACHELOR OF SCIENCE IN AGRICULTURE GENERAL DEGREE OF SOKOINE UNIVERSITY OF AGRICULTURE (SUA), MOROGORO, TANZANIA.

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ABSTRACT

Mungbean, also known as Green gram (*Vigna radiata* L) is an important legume and annual crop with a sweet flavor and a soft texture when cooked . Mungbeans are a rich source of protein, fiber, vitamin B and C, and minerals making them a popular ingredient in many vegetarian and versatility in various culinary applications like soups, stews, curries, and desserts. Mungbean growth and productivity is influenced by its ability to form symbiotic relationships with nitrogen-fixing bacteria known as rhizobia, which convert atmospheric nitrogen into a form that can be readily used by plants, through the formation of nodules on the roots of the Mungbean plant, where the rhizobia reside. The experiment aimed to assess the nodulation potential in different Mungbean varieties for better management of soil fertility. The experimental design used during research experiment was Randomized Complete Block Design (RCBD) with three replications and four treatments (four Mungbean varieties).

Results showed that, there was significant difference on number of nodules both at flowering and pod filling stage at P-value <0.001. TARI GRAM 1 variety exhibited highest number of nodules at flowering and pod filling stage, 20 and 41 nodules, TARI GRAM 2 variety had 15 and 33.3. nodules, Nuru variety had 10.3 and 20 nodules while Imara variety had 11.67 and 26 nodules respectively. This indicated TARI GRAM 1 variety had superior nodulation potential and nitrogen fixation potential to improve soil fertility and crop yield in mungbean cultivation followed by TARI GRAM 2 variety. Therefore, TARI GRAM 1 and TARI GRAM 2 varieties are recommended for farmers looking to enhance soil fertility in Mungbean cultivation. The increased number of nodules on Mungbean plants leads to higher rates of nitrogen fixation efficiency resulting in greater nutrient availability in the soil as well as the overall soil fertility and sustainability.

DECLARATION

I, **PASCHAL**, **LEONARD LENDA** do hereby declare to the senate of Sokoine University of Agriculture that this research project report is my own original work done within the period of registration and that it has neither been submitted nor being concurrently submitted in any other institution for a degree award or any other purpose.

…… Date……

PASCHAL, LEONARD LENDA

(BSc. Agriculture General, candidate)

The above declaration is confirmed by;

…… Date……

DR. BEATRICE MWAIPOPO

(Research Project Supervisor)

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DEDICATION

I would like to dedicate this research project work to my loving father, Mr. Paschal Nzoka and my lovely mother, Elizabeth Paul, who have always been my pillars of strength and support throughout my academic journey. Their unwavering encouragement, guidance, sacrifices and selflessness have made it possible for me to pursue my dreams, and I am forever grateful for everything you have done for me.

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First and foremost, I would like to express my deepest gratitude to the Almighty God for keeping me alive and well and granting me the strength and wisdom to complete my research project successfully. Without His guidance, this project would not have been possible.

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Last but not least, I would like to acknowledge the Higher Education Students' Loan Board (HESLB) for providing me with the financial assistance needed to conduct this research project. Their support made it possible for me to pursue my academic goals and explore new avenues of knowledge and make significant contributions to the field of agriculture. To each and every individual mentioned above, I offer my heartfelt thanks. Your support and encouragement have been invaluable to me and I am truly grateful for all that you have done.

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LIST OF ABBREVIATIONS

ANOVA – Analysis of Variance

CV – Coefficient of Variation

df – degree of freedom

EC – Emulsifiable Concentrate

F-critical – F-tabulated

F-stat. – F-statistic/F-calculated

LSD – Least Significant Difference

ms – Mean sum of squares

NPK – Nitrogen, Phosphorus, Potassium fertilizer

P-value or **F pr –** Probability value

R- Replication

RCBD - Randomized Complete Block Design

ss – Sum of squares

SUA – Sokoine University of Agriculture

T - Treatment

v.r – Variance

CHAPTER ONE

1. INTRODUCTION

1.1 Background information

Mungbean, also known as Green gram (*Vigna radiata* L) is an important legume crop widely cultivated in many tropical and subtropical regions of world, with a high potential for contributing to food security and income generation. It is annual crop with a sweet flavor and a soft texture when cooked (Singh and Yadav, 2016). Mungbeans are a rich source of protein, fiber, vitamin B and C, and minerals; Magnesium, Potassium, Iron, Phosphorous and Zinc, making them a popular ingredient in many vegetarian and versatility in various culinary applications like soups, stews, curries, and desserts (Goyal, 2015).

According to a study by Laswai *et al.* (2015), Mungbean is grown in different regions of Tanzania, particularly in the southern highlands, central zone, and eastern zone but the crop is most grown in Shinyanga, Simiyu, Mwanza, Morogoro and Geita regions. Mungbean crop is commonly cultivated for its nutritional value and as a source of income for smallholder farmers. According to the Tanzania Ministry of Agriculture, the production of Mungbeans increased from 10,000 tons in 2015 to 18,000 tons in 2019. Mungbean production has gained significant attention due to its contribution to food security, income generation, and improved soil quality.

One of the key factors influencing the growth and productivity of Mungbean is its ability to form symbiotic relationships with nitrogen-fixing bacteria known as rhizobia, which convert atmospheric nitrogen into a form that can be readily used by plants, through the formation of nodules on the roots of the Mungbean plant, where the rhizobia reside. Nodulation is a crucial process for nitrogen fixation for optimizing Mungbean yields and reducing the need for nitrogen fertilizers (Singh and Shanmugasundaram, 1993). Mungbean has the ability to form nodules and fix atmospheric nitrogen in a wide range of soil conditions, including those with low fertility and highlighted the importance of inoculating Mungbean seeds with specific strains of rhizobia to enhance nodulation and nitrogen fixation (Mpeba *et al.*, 2010)

Generally, Efforts to improve Mungbean production in Tanzania have focused on promoting the use of high-quality seeds, adopting improved agronomic practices, and enhancing the symbiotic relationship between Mungbean and rhizobia. For example, initiatives such as the Tanzania Agricultural Research Institute (TARI) have been working on developing and promoting effective rhizobial inoculants for Mungbean to improve nodulation and nitrogen fixation in the soil. Therefore, understanding the nodulation potential of different Mungbean genotypes in Tanzania is crucial for maximizing nitrogen fixation for soil fetility management and improving crop productivity.

1.2 PROBLEM STATEMENT AND JUSTIFICATION

1.2.1 Problem Statement

Despite the significance of nodulation, economic and nutritional importance of in Mungbean, limited information is available regarding the nodulation potential of various genotypes. This knowledge gap hinders the identification and selection of Mungbean varieties with superior nodulation abilities, which could lead to enhanced nitrogen fixation and improved crop performance (Singh *et al.,* 2018). Although Mungbean has a strong potential for nitrogen fixation through nodulation, different Mungbean varieties may have varying abilities to establish symbiotic relationships with rhizobia and form nodules (Jain *et al.,* 2016).

This variation can significantly impact the overall nitrogen-fixing capacity of the plant, affecting its growth, yield, and ultimately, its economic value to farmers and understanding this variation is crucial for optimizing nodulation and nitrogen fixation in Mungbean cultivation. The lack of comprehensive assessment and comparison of nodulation efficiency among different Mungbean genotypes hinders the breeding efforts aimed at developing superior cultivars with enhanced nitrogen-fixing capabilities and development of effective management practices geared towards improving nodulation potential and nitrogen fixation in Mungbean genotypes (Zahran, 1999). This calls for a comprehensive assessment of nodulation in Mungbean genotypes adapted to Tanzanian agro-ecological conditions.

The problem of poor nodulation potential in Mungbean genotypes in Tanzania has resulted in low and unstable yields, limiting the potential of this important crop to contribute to food and nutrition security, as well as income generation for smallholder farmers. The current lack of effective nitrogen fixation in Mungbean also contributes to reduced soil fertility, leading to increased reliance on chemical fertilizers that are not only costly but also detrimental to the environment (Kumar *et al.,* 2017). Given the significance of Mungbean in the country, addressing the problem of poor nodulation potential in Mungbean genotypes could contribute to enhancing the sustainability and productivity of Mungbean production in Tanzania.

This gap in the literature highlights the need for a thorough research on assessment of nodulation potential in Mungbean genotypes to better understand the genetic and environmental factors influencing nodulation efficiency and overall soil fertility management. By addressing this gap, the research aims to provide valuable insights into the nodulation potential of different Mungbean genotypes, which can ultimately contribute to the development of improved cultivars with enhanced nitrogen-fixing capabilities for optimizing crop production soil fertility, and ensuring sustainable agriculture in Tanzania.

1.2.2 Justification

The nodulation potential of Mungbean (*V. radiata*) is a crucial factor that determines their ability to fix atmospheric nitrogen through the symbiotic relationship with nitrogen-fixing rhizobacteria. Nodulation is the process by which nodules, specialized structures on the roots of legumes, are formed (Thao and Yamakawa, 2009). This research aims to fill this gap by evaluating and comparing the nodulation potential of different Mungbean varieties under standardized field conditions. The findings of the study will provide valuable insights into the nodulation capacity of these varieties and help farmers and agricultural researchers in selecting appropriate cultivars that can maximize nitrogen fixation and crop productivity.

The assessment of nodulation potential in Mungbean genotypes will aid in identifying genotypes with superior nodulation efficiency can enable the development of Mungbean cultivars with improved nitrogen-fixing capabilities to reduce the reliance on synthetic nitrogenous fertilizers, which have detrimental environmental impacts and contribute to sustainable agriculture (Jain *et al.,* 2016). Also, understanding the genetic variation in nodulation potential can aid in the selection and breeding of Mungbean genotypes that are better adapted to different environmental conditions. This can enhance the productivity of Mungbean cultivation in diverse agro-climatic regions (Sulieman and Tran, 2015).

Furthermore, Mungbean is often grown in nitrogen-deficient soils, making efficient nodulation crucial for maximizing crop productivity (Singh and Reddy, 2011). Understanding the factors influencing nodulation efficiency can help researchers identify strategies to optimize nodulation in Mungbean varieties, leading to more sustainable and productive farming practices, selection and breeding of Mungbean varieties with improved nodulation traits, thus increasing overall crop productivity and sustainability (Ali, 2004).

1.3 OBJECTIVES

1.3.1 General Objective

The general objective of this research is to assess the nodulation potential in different Mungbean genotypes for better management of soil fertility.

1.3.2 Specific Objectives

i. To evaluate and compare the nodulation capacity of selected Mungbean genotypes under field conditions.

ii. To identify Mungbean genotypes with superior nodulation potential and nitrogen fixation capabilities.

CHAPTER TWO

2. LITERATURE REVIEW

2.1 Origin and distribution of Mungbean crop

Mungbean (*Vigna radiata* L.) is believed to have originated from India and has been cultivated for over 7,000 years in Asia (Singh *et al.,* 2017). Over time, Mungbean cultivation has spread to other parts of Asia, Africa, and the Americas, where it is valued for its nutritional benefits and ability to thrive in diverse agro-ecological conditions (Singh and Singh, 2011). The distribution and cultivation of Mungbean are influenced by various factors, including climate, soil fertility, and cultural practices. Mungbean is mainly grown in tropical and subtropical regions, as it requires warm temperatures (25-30°C) for optimum growth and development. However, it can also tolerate a wide range of climatic conditions, from arid to humid environments (Janila *et al.,* 2020).

2.2 Botanical description and classification of Mungbean crop

Mungbean is an annual, herbaceous plant that has a climbing or trailing growth habit with slender, cylindrical, and hairy stems. The plant can reach a height of 30-100 cm and has trifoliate, alternate, leaves with long petioles. The flowers are small and yellow, and the pods are cylindrical and can be green or black. Each flower gives rise to a narrow and straight pod, which contains 6-8 seeds. The seeds are small, ovoid, spherical, and usually green or yellow in color (Minhas and Siddiqi, 2010).

Mungbean belongs to Kingdom Plantae, under the family *Fabaceae* (*Leguminosae*) and is a member of the subfamily *Faboideae*, tribe *Phaseoleae* and is classified under the subfamily *Papilionoideae*, Genus *Vigna* and Species *radiata*. Mungbean is known by various names in different regions, such as Green gram, Golden gram or Moong (Jain *et al.,* 2010).

2.3 Ecological requirements for Mungbean crop production

Mungbean is a warm-season crop adapted to tropical and subtropical regions. It thrives in regions with a temperature range of 20-35°C and requires long days for optimum growth and flowering. It is sensitive to frost and cannot tolerate temperatures below 10°C.

Mungbean prefers well-drained sandy loam to loamy soils with a pH range of 6-7.5. It requires a moderate amount of rainfall (500-900 mm) during its growing period (Ali, 2004).

Furthermore, Mungbean is sensitive to water-logging, so adequate irrigation is necessary, particularly during critical growth stages such as flowering and pod filling. In areas where rainfall is insufficient, supplementary irrigation is required to ensure high yields and quality production. Mungbean also requires full sunlight for optimal growth and development, and shading can reduce yield and quality (Khajudparn and Amponsah, 2010).

2.4 Economic importance of Mungbean crop

Mungbean is an important leguminous crop that is grown primarily for its edible seeds, but its economic importance goes beyond just the food market. Mungbean is also valued for its high protein content and can be used as feed for animals. In addition, Mungbean plants are able to fix nitrogen in the soil, which helps to improve soil fertility and health, making it an important crop in sustainable agricultural systems (FAO, 2019).

Mungbean production plays a critical role in providing income and livelihoods for millions of smallholder farmers in Tanzania and in the world general. Mungbean is an important cash crop in these regions, and its cultivation contributes significantly to the agricultural economy. The crop also has great potential for income generation and poverty reduction due to its short gestation period and high market demand. and exported to various countries contributing to international trade and economic development and economic stability making it an attractive option for smallholder farmers (Sarker *et al.,* 2016).

2.5 Nodulation in Mungbean

Nodulation, the process by which nitrogen-fixing nodules are formed on the roots of legume plants, plays a crucial role in the overall productivity and sustainability of Mungbean cultivation (Thao and Yamakawa, 2009). Mungbean forms a symbiotic relationship with specific rhizobia bacteria that can fix atmospheric nitrogen in root nodules. The nodules, typically located on primary and lateral roots, are the sites of nitrogen fixation. The nodules provide a symbiotic relationship between the plant and the bacteria, where the plant provides carbohydrates to the bacteria, and the bacteria fix atmospheric nitrogen into a form that the plant can use (Liyanage *et al.*, 2019).

2.6 Nodulation potential in Mungbean

Nodulation potential refers to the capacity of Mungbean varieties, to form nodules on their roots in association with nitrogen-fixing bacteria called rhizobia. These nodules house specialized cells that facilitate the conversion of atmospheric nitrogen into a usable form for the plant, a process known as biological nitrogen fixation. This symbiotic relationship between the legume and rhizobia contributes to nitrogen cycling in agricultural systems and reduces the reliance on chemical fertilizers (Singh *et al.,* 2018).

According to Singh and Reddy (2011) described that the nodulation potential of Mungbean genotypes can vary, with some genotypes exhibiting better nodulation and nitrogen fixation capabilities compared to others depending on the presence of compatible rhizobia strains in the soil and the overall plant health and vigor.

2.7 Factors affecting nodulation potential in Mungbean genotypes

The efficiency of nodulation and nitrogen fixation in Mungbean is influenced by both genetic and environmental factors. One key factor is the availability of compatible rhizobial strains in the soil. Wani *et al.* (2019) highlighted the importance of selecting rhizobial strains that are specific to Mungbean, as they exhibit better compatibility, resulting in efficient nodulation. This emphasizes the significance of rhizobial strain selection for promoting nodulation development.

In addition to rhizobial compatibility, soil fertility plays a vital role in nodulation. Soil nutrient availability, particularly phosphorus, has been found to influence nodulation in Mungbean. Dhungana *et al.* (2017) reported that phosphorus deficiency in soil negatively affects nodulation development in Mungbean. The adequate phosphorus levels promote nodulation by enhancing the availability of energy resources for both rhizobia and plants.

The genetic makeup of the Mungbean genotype also plays a role in nodulation potential, as some genotypes are more effective in forming nodules than others and breeding efforts are focused on developing genotypes with improved nodulation and nitrogen fixation capabilities. Furthermore, environmental factors such as temperature, light intensity, and moisture also affect nodulation development in Mungbean. The impact of various environmental conditions on nodule formation such as drought, high temperature and salinity, can reduce the nodulation potential in Mungbean (Singh and Shanmugasundaram, 1993).

The authors emphasized the need for favorable environmental conditions to ensure optimal nodulation development.

CHAPTER THREE

3. MATERIALS AND METHODS

3.1 LOCATION

The research experiment was conducted at Crop Museum located in Sokoine University of Agriculture (SUA) Morogoro region, Tanzania. The area was found at Latitude of 06˚S 50˚S, Longitudes 37˚S 39˚E and Altitude of 525 M above the sea level. The soil of clay-loam with pH of 5.1 Rainfall ranges from 750-1050 mm per annum and temperature range between 15˚C-35˚C.

3.2 MATERIALS

The materials that used during research experiment were Mungbean seeds of four different genotypes namely; Imara, Nuru, TARI GRAM-1 and TARI GRAM-2 Mungbean varieties for crop establishment, CUTTER 112 EC pesticide for pest control and NPK planting fertilizer for soil fertilization.

3.3 METHODS

3.3.1 Land preparation

The field for this experiment was prepared by both primary and secondary tillage. Primary tillage was done using disc plough mounted on farm tractor to turn over the soil and break up the clumps and incorporate weeds into the soil. Additionally, secondary tillage was done using hand hoe in which all existing debris was be removed to provide a clean surface for the experiment. Finally, the tilled land was leveled and seedbeds were formed using hand to allow for better water infiltration and drainage.

3.3.2 Experimental design and Layout

The experimental design used during research experiment was Randomized Complete Block Design (RCBD) with three replications and four treatments (four Mungbean varieties) which were assigned randomly to the experimental units of each block.

The experimental field was divided into 12 plots, each plot measured 1.8m width x 1.5m length, left alley spaces of 0.5m between plots in a replication, 0.8m alley spacing between the replications, resulted to 8m length by 8m wide with the total experimental area of 64m^2. A total of 4 rows of plants were planted on each plot by spacing of 15cm between the plants and 45cm between the rows. One seed was sown per hill. This resulted to a total of 10 plants per row and 40 plants per each plot. Therefore, total experimental area accommodated a total of 480 plants.

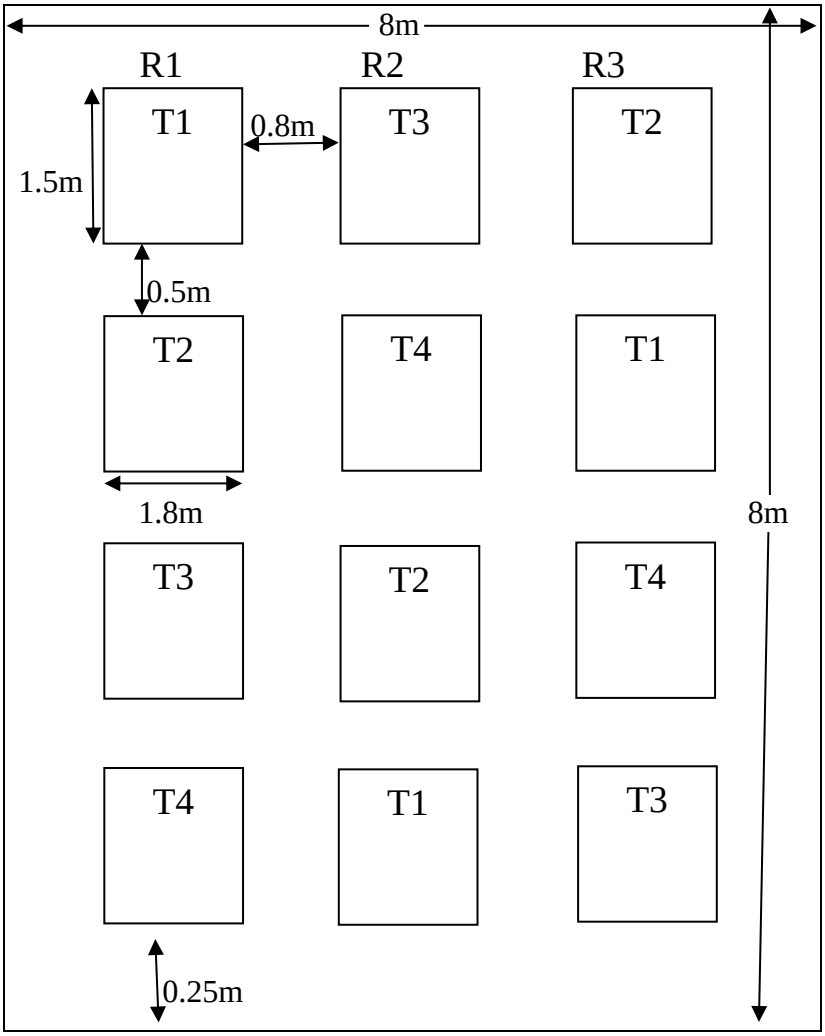


Figure 1: Experimental Layout

KEY

T1 = Treatment 1(Nuru Mungbean variety).

T2 = Treatment 2 (Imara Mungbean variety).

T3 = Treatment 3 (TARI GRAM-1 Mungbean variety).

T4 = Treatment 4 (TARI GRAM-2 Mungbean variety).

R1=Replication 1.

R2=Replication 2.

R3=Replication 3.

3.4 AGRONOMIC MANAGEMENTS

Primary and secondary tillage were done to break off the compact surface and to loosen the soil mass, so as to enable the roots to penetrate and spread into the soil. During the experiment, NPK fertilizer was applied in each experimental plot two weeks from seedling emergence in which 5 grams of NPK fertilizer were applied per seedling by basal application method. Additionally, surface irrigation by hand cane was evenly applied to each plot of the experiment to ensure optimal moisture content availability for optimal growth and development of plants twice a day. Furthermore, manual weeding was done using a hand hoe to remove any existing weeds to prevent competition of weeds with crops for growth resources such as nutrients, water, space and sunlight. Lastly, insect pests were controlled by chemical means through two times application pesticide (CUTTER 112 EC) using Knapsack sprayer pump.

3.5 DATA COLLECTION

3.5.1 Plant sampling

The destructive sampling for data parameters collection was used, in which four plants in each plot (treatment) were uprooted twice at flowering (42 days from planting) and pod filling stages (56 days from planting). Each plot was sufficiently watered to obtain high moisture before uprooting of plants to avoid breakage of plant roots and remaining under the soil.

3.5.2 Plant height

During data collection from representative samples (four plants) for each plot at both flowering and pod filling stages, plant heights were measured and recorded in centimeters from the base of the plant to the tip of the plant stem using a ruler.

3.5.3 Leaf length

During data collection from four representative samples from each plot at both flowering and pod filling stages, the lengths of longest leaves were measured and recorded in centimeters from the base of the leaf petiole at the stem of plant to the tip of the leaf using a ruler.

3.5.4 Plant biomass

During data collection from four representative samples from each plot at both flowering and pod filling stages, fresh plant biomasses were measured and recorded in grams by harvesting all the above ground materials (stem, leaves, flowers and pods) using a weight balance.

3.5.5 Root length

During data collection from four representative samples from each plot at both flowering and pod filling stages, root lengths were measured and recorded in centimeters from the junction of plant stem base and top of root to the tip of the longest root using a ruler.

3.5.6 Number and colour of nodules

In evaluation of number of nodules from four representative samples from each plot at both flowering and pod filling stages, plant roots were gently washed in water to remove all soil debris and muds and all nodules were counted at both tap and lateral roots. Additionally, the colour of each nodule was evaluated and recorded at each stage by direct observation by eyes.

3.5.7 Size and distribution of nodules

In evaluation of size of nodules from four representative samples from each plot at both flowering and pod filling stages, the sizes of all counted nodules were thoroughly assessed and categorized as small, medium or large nodule. Also, nodule distribution patterns on the roots were assessed by categorizing the position of nodules (on tap root or on lateral roots).

3.6 DATA ANALYSIS

The data collected were subjected to statistical analysis of variance (ANOVA) to compare the tabulated F-value and computed F-value at 5% significance level to evaluate the nodulation potential among Mungbean genotypes and treatments were separated by Tukey Mean-Difference (TMD) at probability value of $P \leq 0.05$ using GenStat computer programmed software of 15^{th} edition.

CHAPTER FOUR

4. RESULTS

4.1. Plant Height

According to table 1, both at flowering and flowering stage, there was no significant difference on plant height among Mungbean varieties observed at the P = 0.910 and 0.223 respectively. The average plant height mean at flowering and pod filling stage was 20.73 cm and 33.6 cm respectively where at flowering stage, the highest value was experienced on TARI GRAM 1 variety and lowest value on TARI GRAM 2 variety. But, during pod filling stage, the highest value was experienced on TARI GRAM 1 variety and lowest value experienced on Imara variety. Additionally, there was no confidence to reject null hypothesis since F-statistic at both flowering and flowering stage was 0.17 and 1.95 respectively, were less than F-critical (4.76).

Table 1: Results of plant heights among varieties at different growth stages

Analysis of variance (ANOVA)	Plant height (cm)	
	At Flowering stage	**At Pod filling stage**
T1 (Nuru Variety)	20.60[a]	32.43[a]
T2 (Imara Variety),	20.63[a]	30.47[a]
T3 (TARI GRAM 1 Variety)	21.23[a]	36.97[a]
T4 (TARI GRAM 2 Variety)	20.47[a]	34.63[a]
Grand mean	20.73	33.6
% CV	6.8	10.3
LSD	2.825	6.94
F-statistic (v.r)	0.17	1.95
F-critical $_{(0.05)}$	4.76	4.76
P-value	**0.910**	**0.223**

4.2 Leaf Length

Results of leaf length at flowering stage revealed that, there was no significant difference among varieties observed at the P = 0.537 and grand mean leaf length of 29.51 cm. The highest leaf length value was experienced on TARI GRAM 1 variety and lowest leaf length value on TARI GRAM 2 variety. Also, there was no confidence to reject null hypothesis at flowering stage since F-statistic (0.80) was less than F-critical (4.76). But, during pod filling stage, there was very significant difference on leaf length among Mungbean varieties observed at the P = 0.007 and grand mean leaf length of 34.12 cm. The highest leaf length value was experienced on TARI GRAM 1 variety and lowest value on TARI GRAM 2 variety. Consider table 2 below;

Table 2: Results of leaf lengths among varieties at different growth stages

Analysis of variance (ANOVA)	Leaf length (cm)	
	At Flowering stage	At Pod filling stage
T1 (Nuru Variety)	30.73[a]	37.03[c]
T2 (Imara Variety),	29.27[a]	32.10[ab]
T3 (TARI GRAM 1 Variety)	30.10[a]	35.67[bc]
T4 (TARI GRAM 2 Variety)	27.93[a]	31.70[a]
Grand mean	29.51	34.12
% CV	7.9	4.0
LSD	4.673	2.709
F-statistic (v.r)	0.80	11.33
F-critical $_{(0.05)}$	4.76	4.76
P-value	**0.537**	**0.007**

4.3 Plant Biomass

According to table 3, at flowering stage results revealed that, there was no significant difference on plant biomass among Mungbean varieties observed at the P = 0.208 and grand mean biomass of 50.70 grams. The highest plant biomass value was experienced on TARI GRAM 1 variety and lowest plant biomass value on TARI GRAM 2 variety. Also, there was no confidence to reject null hypothesis at flowering stage since F-statistic (2.06) was less than F-critical (4.76). But, at pod filling stage, significant difference on plant biomass among varieties was observed at the P = 0.051 and grand mean biomass of 75.2 grams. The highest plant biomass value was experienced on TARI GRAM 1 variety and lowest plant biomass value on Imara variety.

Table 3: Results of plant biomass among varieties at different growth stages

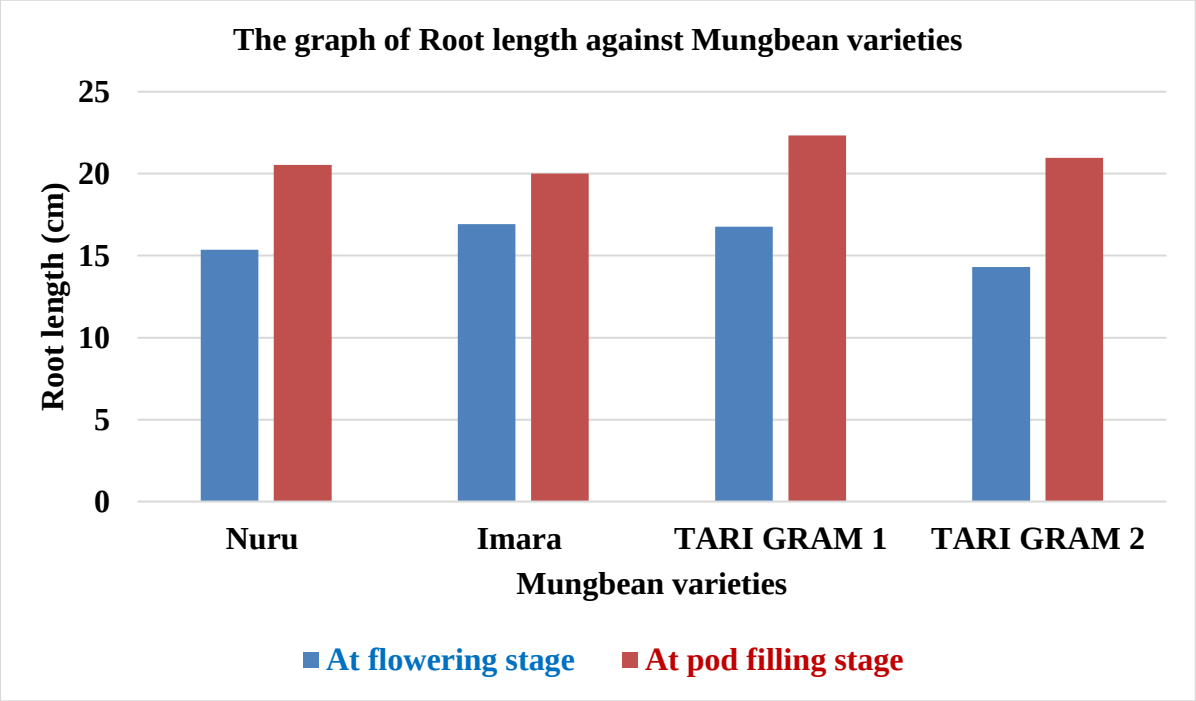
Analysis of variance (ANOVA)	Plant biomass (g)	
	At Flowering stage	At Pod filling stage
T1 (Nuru Variety)	50.00[a]	72.33[ab]
T2 (Imara Variety),	52.00[a]	70.67[a]
T3 (TARI GRAM 1 Variety)	56.33[a]	82.67[b]
T4 (TARI GRAM 2 Variety)	44.33[a]	75.00[ab]
Grand mean	50.7	75.2
% CV	11.9	5.6
LSD	12.02	8.47
F-statistic (v.r)	2.06	4.70
F-critical $_{(0.05)}$	4.76	4.76
P-value	**0.208**	**0.051**

4.4 Root Length

According to figure 2, results of root length both at flowering and pod filling stage showed that, there was no significant difference among Mungbean varieties observed at the P = 0.058 and 0.451 respectively. The average root length mean at flowering and pod filling stage was 15.84 cm and 20.96 cm respectively. At flowering stage, the highest root length value was experienced on Imara variety and lowest root length value on TARI GRAM 2 variety.

But, at pod filling stage, the highest root length value was experienced on TARI GRAM 1 variety and lowest root length value experienced on Imara variety. Moreover, there was no confidence to reject null hypothesis since F-statistic both at flowering and flowering stage was 4.40 and 1.01 respectively, were less than F-critical (4.76). Consider figure 2 below;

Figure 2: Results of root lengths among varieties at different growth stages



4.5 Number of Nodules

In evaluation of number of nodules both at flowering and pod filling stage results showed that, there was very significant difference among Mungbean varieties observed at the P = <0.001. The average number of nodules mean at flowering and pod filling stage was 14.25 and 30.08 respectively. The highest number of nodule value both at flowering and pod filling stage was experienced on TARI GRAM 1 variety which showed 20 and 41 nodules respectively.

But, the lowest number of nodule value both at flowering and pod filling stage was experienced on Nuru variety which showed 10.33 and 20 nodules respectively. Moreover, there was no confidence to reject null hypothesis since F-statistic both at flowering and flowering stage was 4.40 and 1.01 respectively, were less than F-critical (4.76). Consider table 4 below;

Table 4: Results of number of nodules among varieties at different growth stages

Analysis of variance (ANOVA)	Number of nodules	
	At Flowering stage	**At Pod filling stage**
T1 (Nuru Variety)	10.33[a]	20.00[a]
T2 (Imara Variety),	11.67[a]	26.00[ab]
T3 (TARI GRAM 1 Variety)	20.00[c]	41.00[c]
T4 (TARI GRAM 2 Variety)	15.00[b]	33.33[bc]
Grand mean	14.25	30.08
% CV	7.5	9.8
LSD	2.132	5.910
F-statistic (v.r)	48.85	28.35
F-critical $_{(0.05)}$	4.76	4.76
P-value	**<0.001**	**<0.001**

4.6 Colour of Nodules

In assessment of colour of nodules both at flowering and pod filling stage, there was variation of nodule colour among Mungbean varieties. At flowering stage, Nuru and Imara varieties appeared with whitish colour on the outer layer (skin of nodules) while TARI GRAM 1 and TARI GRAM 2 varieties appeared with light brown colour on the outer layer (skin of nodules). However, all varieties, Nuru, Imara, TARI GRAM 1 and TARI GAM 2 showed similar pinkish colour inside the nodules. At pod filling stage, Nuru and TARI GRAM 2 varieties remained as with whitish colour as at flowering stage on the outer layer (skin of nodules) while Imara and TARI GRAM 1 changed from light brown to brown colour on the outer layer (skin of nodules). All varieties, Nuru, Imara, TARI GRAM 1 and TARI GAM 2 showed similar colour inside the nodules but changed from pinkish to reddish colour (nodule fluid). Consider table 5 below;

Table 5: Results of colour of nodules among varieties at different growth stages

Mungbean varieties (Treatments)	Colour of nodules			
	At flowering stage		**At pod filling stage**	
	Skin colour	**Fluid colour**	**Skin colour**	**Fluid colour**
T1 (Nuru Variety)	Whitish	Pinkish	Whitish	Reddish
T2 (Imara Variety),	Light brown	Pinkish	Brown	Reddish
T3 (TARI GRAM 1 Variety)	Light brown	Pinkish	Brown	Reddish
T4 (TARI GRAM 2 Variety)	Whitish	Pinkish	Whitish	Reddish

4.7 Size of Nodules

In evaluation of size of nodules, nodules were categorized into small, medium and large sized. At flowering stage, the results showed that, there was no significant difference on small sized nodules among varieties observed at the P = 0.439. But, there was significant difference on medium and large sized nodules among varieties observed at the P = 0.004 and 0.005 respectively. TARI GRAM 1 variety experienced highest value of medium and large sized nodules, 8.3 and 4.6 nodules respectively, over all varieties as showed in the table 6.

However, at pod filling stage, there no significant difference both on small, medium and large sized nodules among varieties observed at the P = 0.601, 0.132 and 0.057 respectively. At this stage, TARI GRAM 1 variety experienced highest value of medium and large sized nodules, 15.3 and 18 nodules respectively, while Nuru variety experienced lowest value of medium and large sized nodules, 9.7 and 4.7 nodules respectively over all varieties. Consider table 6 below;

Table 6: Results of size of nodules among varieties at different growth stages

Analysis of variance (ANOVA)	**Size of nodules**					
	At Flowering stage			**At Pod filling stage**		
	Small	**Medium**	**Large**	**Small**	**Medium**	**Large**
T1 (Nuru Variety)	6.667^{a}	2.667^{a}	1.000^{a}	5.667^{a}	9.67^{a}	4.667^{a}
T2 (Imara Variety),	6.667^{a}	4.667^{ab}	0.333^{a}	8.333^{a}	10.00^{a}	7.667^{ab}
T3 (TARI GRAM 1 Variety)	6.667^{a}	8.333^{c}	4.667^{b}	7.667^{a}	15.33^{a}	18.000^{b}
T4 (TARI GRAM 2 Variety)	8.333^{a}	6.333^{bc}	0.333^{a}	8.667^{a}	16.00^{a}	9.000^{ab}
Grand mean	7.08	5.58	1.58	7.58	12.8	9.8
% CV	20	21.3	62.3	37.5	27.5	47.9
LSD	2.825	2.378	1.970	5.680	7.01	9.41
F-statistic (v.r)	1.04	13.71	13.34	0.67	2.79	4.45
F-critical $_{(0.05)}$	4.76	4.76	4.76	4.76	4.76	4.76
P-value	**0.439**	**0.004**	**0.005**	**0.601**	**0.132**	**0.057**

4.8 Distribution of nodules

It was evaluated by percentage concentration on tap root and secondary roots (lateral roots). Distribution of nodules both at flowering and flowering stage, there was no significant difference among Mungbean varieties observed at the P = 0.819 and 0.855 respectively.

At flowering stage, the average percentage distribution mean on tap root and lateral roots was 63.8 and 36.2 respectively, indicated that more nodules were concentrated on tap root than lateral roots as showed on figure 3 below. But, at pod filling stage, the average percentage distribution mean on tap root and on lateral roots was 30.5 and 69.5 respectively, indicated that more nodules were concentrated on lateral roots than on tap root as showed on figure 4 below.

Figure 3: The graph of results of nodule distributions among varieties at flowering stage

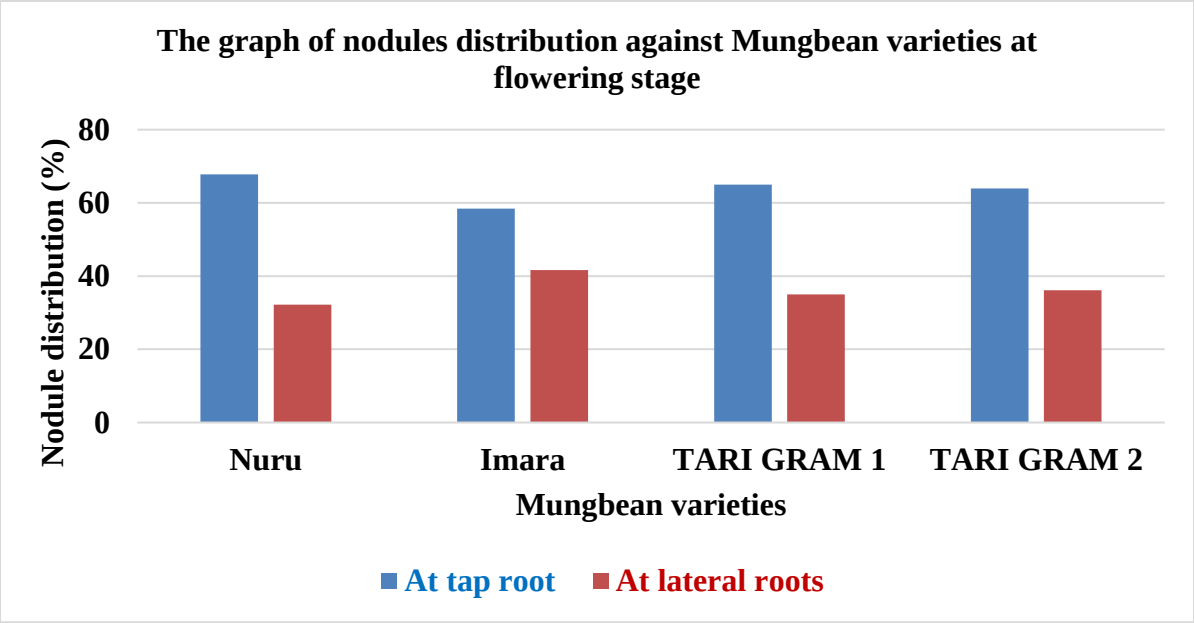
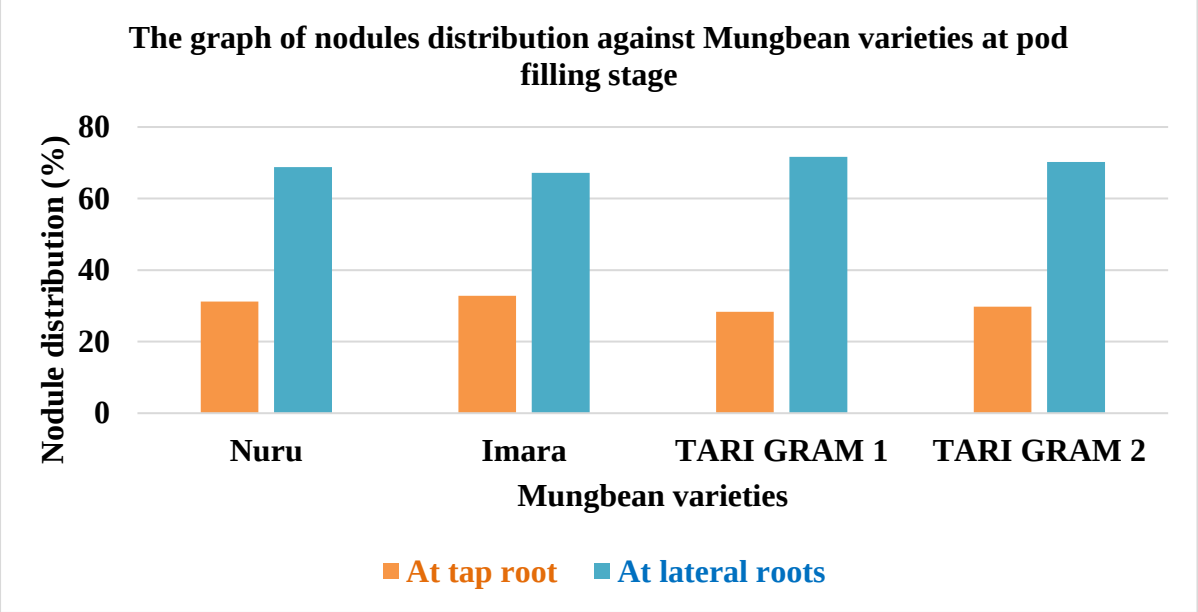


Figure 4: The graph of results of nodule distributions among varieties pod filling stage



CHAPTER FIVE

5. DISCUSSIONS

5.1 To evaluate and compare the nodulation capacity of selected Mungbean genotypes under field conditions

For the evaluation and comparison of the capacity of different Mungbean genotypes to form nodules, different data parameters relating to growth and nodulation potential of Mungbean at both flowering and pod filling stages are discussed below based on the results obtained;

5.1.1 The influence of plant height on plant growth and potential nodulation

Results from plant heights showed that there was no significant difference on plant heights among treatments at both flowering and pod filling stages. This indicated that all treatments were similar (same) in plant heights at either stage. The lack of significant difference on heights of plants between varieties indicated that nodulation potential was influenced by other factors specific to each variety rather than plant heights. However, it was observed highly significant increase of plant heights in both treatment between flowering stage and pod filling stage. This shift in growth pattern can be attributed to the fact that during the pod development and filling stages, the plant allocates more resources towards stem elongation and branches for supporting the structural integrity of the plant. This helps to support the weight of the developing pods and facilitating efficient nutrient transport to the developing pods in order to facilitate seed production (Khan *et al*., 2018).

5.1.2 The influence of leaf length on plant growth and potential nodulation

Results of leaf length showed that there was no significant difference on plant heights among treatments at flowering stage. This indicated that all treatments were similar leaf lengths at flowering stage. Leaves are the primary site for photosynthesis, which provides the energy and resources needed for nitrogen fixation in the nodules. During the vegetative and flowering stages, plants allocate more resources towards leaf growth in order to maximize photosynthesis. In contrast, at pod filling stage, there was a significant difference on leaf heights among treatments. Nuru variety showed highest leaf length followed by TARI GRAM 1 variety while Imara and TARI GRAM 2 varieties both showed near equal and lowest leaf lengths. The highest leaf length in Nuru variety was attributed by better nutrient uptake and canopy development and more allocation of resources towards leaf growth for producing sugars through photosynthesis, which are then transported to the roots and nodules to support nitrogen fixation (Awan *et al*., 2017).

5.1.3 The influence of plant biomass on plant growth and potential nodulation

The results of plant biomass at flowering stage revealed that, there was no significant difference on plant biomass among treatments, indicated that all treatments were similar on plant biomass. However, at pod filling stage, there was significant difference on plant biomass among treatments in which TARI GRAM 1 variety showed highest leaf length followed by Nuru and TARI GRAM 2 varieties which both showed near equal leaf lengths while Imara variety had lowest plant biomass. This indicated that TARI GRAM 1 variety has superior nodulation potential and nitrogen fixation, resulted in enhanced growth and biomass accumulation compared to other varieties. The higher plant biomass in TARI GRAM 1 was associated with increased nodule formation and nitrogen fixation since the larger plant biomass provides more carbon compounds to support the growth and activity of the rhizobia in the nodules, leading to more effective nitrogen fixation (Kharub *et al*., 2012).

5.1.4 Number and size of nodules in relation to nitrogen fixation and nodulation

The results from evaluation of number of nodules at both flowering and pod filling stages, showed that, there was highly significant difference of number of nodules among the varieties. TARI GRAM 1 variety experienced highest number of nodules followed by TARI GRAM 2, while Nuru and Imara varieties showed lowest number of nodules in which both showed near equal number of nodules. The variation in number of nodules at both stages suggested that different Mungbean varieties had varying capacities for nodulation. The number of nodules in mungbean plants is directly correlated with their nodulation potential. These nodules are essential for biological nitrogen fixation, whereby atmospheric nitrogen is converted into a form that the plant can utilize for growth and development. The number of nodules on a plant is indicative of its ability to efficiently fix nitrogen from the atmosphere and convert it into a usable form by plants (Gupta and Kaur, 2018).

Furthermore, in evaluation of size of nodules, there was high proportion of small nodules in all genotypes except for TARI GRAM 1 variety where there was high proportion of medium nodules at flowering stage. Again, TARI GRAM 1 variety showed highest proportion of large nodules than all other genotypes at this stage. In contrast, at pod filling stage, there was high proportion of medium nodules in all genotypes except for TARI GRAM 1 where there was high proportion of large nodules. Also, TARI GRAM 1 variety showed lowest proportion of small nodules than all other treatments at pod filling stage. This indicated that TARI GRAM 1 variety had superior nodulation potential and nitrogen fixation capabilities compared to TARI GRAM 2, Nuru and Imara varieties.

5.1.5 Influence of root length on plant growth and potential nodulation

Results from root length showed that there was no significant difference on root length among treatments at both flowering and pod filling stages. This indicated that all treatments were equal in root lengths at both stages. However, root lengths at both stages were observed to be long enough to support nutrients uptake by plants and formation of nodules by symbiotic nitrogen fixing bacteria among treatments. The length and density of roots impact the ability of rhizobia to colonize the root system and form nodules for nitrogen fixation. Longer roots provide a larger surface area for rhizobia to establish a symbiotic relationship with the plant, resulting in increased nodulation potential and nitrogen fixation capacity and accessibility of nutrients, water, and oxygen to the nodules (Rahman *et al*., 2016).

5.1.6 Distribution of nodules in relation to nitrogen fixation and nodulation

During the flowering stage, the distribution of nodules on the roots was typically observed most concentrated and abundant on the primary root (tap root) and least abundant on the lateral roots for both genotypes. This indicated that all varieties had the similar spatial arrangement of nodules at this stage since there was no significance variation among genotypes. In contrast, during the pod filling stage, distribution of nodules was concentrated on lateral roots and least abundant on the tap root for both genotypes. This redistribution pattern ensures that the plant has a sufficient nitrogen supply to support the increased nutrient demand during pod development and filling, and high metabolic activity of the plant during this stage, making it essential for nodules to be distributed strategically on the root system (Malhotra *et al*., 2011).

5.1.7 Variation of colour of nodules among mungbean genotypes

The results showed that, there was variation of nodule colour among genotypes at both flowering and pod filling stages. At flowering stage, Nuru and TARI GRAM 2 genotypes showed whitish colour on the skin of nodules while Imara and TARI GRAM 1 genotypes appeared with light brown colour. However, all genotypes showed similar pinkish colour inside the nodules. At pod filling stage, Nuru and TARI GRAM 2 genotypes remained as with whitish colour as at flowering stage on skin of nodules while Imara and TARI GRAM 1 genotypes changed from light brown to brown colour on skin of nodules. This indicated that the variation of skin colour of nodules was mainly attributed by growth stages and genetic makeup of the particular genotype. Moreover, all genotypes showed similar colour inside the nodules (colour of fluid of nodules) but changed from pinkish to reddish colour at the pod filling stage. The reddish was color due to the presence of leghemoglobin that acts as an oxygen carrier in the nodule, facilitating the transfer of oxygen to the nitrogen-fixing bacteria for efficient fixation of atmospheric nitrogen into a form that can be utilized by the plant (Sulieman *et al*, 2013).

5.2 To identify Mungbean genotypes with superior nodulation potential and nitrogen fixation capabilities.

For identification of Mungbean genotypes with superior nodulation potential and nitrogen fixation capabilities, the results of the experiment indicated that there were significant differences in the nodulation potential of different Mungbean varieties. At flowering stage, TARI GRAM 1 variety experienced highest number of nodules (20 nodules), followed by TARI GRAM 2 (15 nodules), while Nuru and Imara varieties showed lowest number of nodules which were 12 and 10 number of nodules respectively. Similarly, at pod filling stage, TARI GRAM 1 genotype experienced highest number of nodules (41 nodules), followed by TARI GRAM 2 (33 nodules) while Nuru and Imara varieties showed lowest number of nodules which were 26 and 20 number of nodules respectively. These findings suggested that TARI GRAM 1 variety has superior nodulation potential and is likely to fix nitrogen more effectively compared to the other varieties.

Additionally, it was also identified that, TARI GRAM 1 variety had the highest plant biomass at both flowering and pod filling stage, indicating that it was able to fix more nitrogen and produce more biomass compared to the other varieties. This also suggested that TARI GRAM 1 has a superior ability to utilize nitrogen and grow efficiently. Furthermore, TARI GRAM 2 variety also showed good performance in terms of nodulation potential, with a high number of nodules at both flowering and pod filling stages. TARI GRAM 2 had the second highest plant biomass at pod filling stage, indicating that it is also a strong nitrogen fixer. On the other hand, Nuru and Imara varieties had lower plant biomass and fewer nodules, suggested that they had not efficient in nitrogen fixation compared to TARI GRAM 1 and TARI GRAM 2 varieties. Therefore, TARI GRAM 1 and TARI GRAM 2 varieties of Mungbean were identified as genotypes with superior nodulation potential and nitrogen fixation capabilities than others.

CHAPTER SIX

6. CONCLUSION AND RECOMMENDATIONS

6.1 CONCLUSION

Based on the major findings of this experiment, it can be concluded that there are significant differences in nodulation potential among different Mungbean varieties. The number of nodules in Mungbean plants is directly correlated with their nodulation potential. The increased number of nodules on Mungbean plants leads to higher rates of nitrogen fixation efficiency and overall plant growth, resulting in greater nutrient availability in the soil. This, in turn, can positively affect the growth and productivity of other crops grown in rotation with Mungbean, as well as contribute to overall soil fertility and sustainability. Through the process of biological nitrogen fixation, Mungbean plants with a higher number of nodules can effectively increase the amount of fixed nitrogen in the soil. This fixed nitrogen is subsequently released into the soil upon decomposition of the plant material, enhancing the nutrient content of the soil and providing a source of nitrogen for other plants in the ecosystem. This can have positive effects on crop yields and can help reduce the need for external nitrogen inputs, such as chemical fertilizers. In addition, the enhanced soil fertility resulting from increased nodulation in Mungbean plants can also promote the growth of beneficial soil microorganisms and improve soil structure and fertility over time.

6.2 RECOMMENDATIONS

i) Farmers should preferentially plant Mungbean varieties with high nodulation potential, such as TARI GRAM1 and TARI GRAM 2, for enhanced soil fertility management. These varieties have higher plant biomass and increased nodulation capacity.

ii) Further research is needed to understand the specific factors influencing nodulation potential in mungbean varieties. This will help in identifying the genetic traits responsible for superior nodulation and nitrogen fixation varieties.

iii) Crop rotation with leguminous crops, including mungbean, should be encouraged to improve soil fertility. Leguminous crops have the ability to fix nitrogen from the atmosphere and reducing the reliance on synthetic fertilizers.

iv) Regular monitoring of nodulation status in Mungbean crops should be conducted to assess the effectiveness of nitrogen fixation and adjust management practices accordingly.

v) Extension services and agricultural organizations should provide training and resources to farmers on selecting and managing Mungbean varieties with high nodulation potential to optimize soil fertility and crop yield.

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APPENDICES

Appendix 1: Data parameters collected and recorded at Flowering stage (42 days from planting, equals to 6 weeks)

Treatment (Variety)	Replication (Block)	Data Parameters Collected											
		Plant height (cm)	Leaf length (cm)	Plant biomass (g)	Root length (cm)	Number of nodules	Size of Nodules			Colour of Nodules		Distribution of Nodules	
							Small	Medium	Large	Outer Colour	Inner Colour	Tap Root	Lateral Roots
T1 NURU	R1	19.6	28.7	44	15.1	9	7	2	0	Whitish	Pinkish	6	3
	R2	19.7	30.1	48	15.8	10	6	3	1	Whitish	Pinkish	7	3
	R3	22.5	33.4	58	15.2	12	7	3	2	Whitish	Pinkish	8	4
T2 IMARA	R1	20.3	28.6	46	16.3	10	6	4	0	Light brown	Pinkish	7	3
	R2	20.5	31.3	54	16.9	13	8	4	1	Light brown	Pinkish	5	8
	R3	21.1	27.9	56	17.6	12	6	6	0	Light brown	Pinkish	8	4
T3 TARI GRAM 1	R1	19.8	27.8	47	14.0	17	7	7	3	Light brown	Pinkish	11	6
	R2	23.4	33.1	63	18.5	21	9	7	5	Light brown	Pinkish	14	7
	R3	20.5	29.4	59	17.8	22	4	12	6	Light brown	Pinkish	14	8
T4 TARI GRAM 2	R1	20.7	29.9	46	13.5	14	7	6	1	Whitish	Pinkish	7	7
	R2	21.2	27.5	49	14.6	16	10	6	0	Whitish	Pinkish	12	4
	R3	19.5	26.4	38	14.8	15	8	7	0	Whitish	Pinkish	10	5

Appendix 2: Data parameters collected and recorded at Pod filling stage (56 days from planting, equals to 8 weeks)

Treatment (Variety)	Replication (Block)	Data Parameters Collected											
		Plant height (cm)	Leaf length (cm)	Plant biomass (g)	Root length (cm)	Number of nodules	Size of Nodules			Colour of Nodules		Distribution of Nodules	
							Small	Medium	Large	Outer Colour	Inner Colour	Tap Root	Lateral Roots
T1 NURU	R1	27.8	35.2	66	18.7	17	4	10	3	Whitish	Reddish	5	12
	R2	30.5	36.8	69	19.3	20	10	9	1	Whitish	Reddish	5	15
	R3	39.0	39.1	82	23.6	23	3	10	10	Whitish	Reddish	9	14
T2 IMARA	R1	28.0	31.6	65	19.9	23	6	12	5	Brown	Reddish	7	16
	R2	30.3	33.8	70	19.5	25	12	5	8	Brown	Reddish	7	18
	R3	33.1	30.9	77	20.6	30	7	13	10	Brown	Reddish	12	18
T3 TARI GRAM 1	R1	33.1	33.6	76	20.9	38	8	13	17	Brown	Reddish	11	27
	R2	41.3	38.0	88	24.5	45	8	15	22	Brown	Reddish	14	31
	R3	36.5	35.4	84	21.6	40	7	18	15	Brown	Reddish	10	30
T4 TARI GRAM 2	R1	33.5	30.8	69	19.4	34	10	11	14	Whitish	Reddish	9	25
	R2	37.5	32.7	80	22.5	35	6	20	9	Whitish	Reddish	13	22
	R3	32.9	31.6	76	21.0	31	10	17	4	Whitish	Reddish	8	23

Appendix 3: Table of F-values at 5% level of significance

F-table of Critical Values of α = 0.05 for F(df1,df2)									
	DF1=1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
DF2=1	161.45	199.50	215.71	224.58	230.16	233.99	236.77	238.88	240.54
2	18.51	19.00	19.16	19.25	19.30	19.33	19.35	19.37	19.38
3	10.13	9.55	9.28	9.12	9.01	8.94	8.89	8.85	8.81
4	7.71	6.94	6.59	6.39	6.26	6.16	6.09	6.04	6.00
5	6.61	5.79	5.41	5.19	5.05	4.95	4.88	4.82	4.77
6	5.99	5.14	**4.76**	4.53	4.39	4.28	4.21	4.15	4.10
7	5.99	4.74	4.35	4.12	3.97	3.87	3.79	3.73	3.68
8	5.32	4.46	4.07	3.84	3.69	3.58	3.50	3.44	3.39
9	5.12	4.26	3.86	3.63	3.48	3.37	3.29	3.23	3.18
10	4.96	4.10	3.71	3.48	3.33	3.22	3.14	3.07	3.02
11	4.84	3.98	3.59	3.36	3.20	3.09	3.01	2.95	2.90
12	4.75	3.89	3.49	3.26	3.11	3.00	2.91	2.85	2.80
13	4.67	3.81	3.41	3.18	3.03	2.92	2.83	2.77	2.71
14	4.60	3.74	3.34	3.11	2.96	2.85	2.76	2.70	2.65
15	4.54	3.68	3.29	3.06	2.90	2.79	2.71	2.64	2.59

Note: DF1 = Degree of freedom of treatments
DF2 = Degree of freedom of error/residual

Appendix 4: Amplitude of the ranges of Coefficients of Variation (CV)

Coefficients of Variation (CV) Range		**Implication on Statistical Results**
CV value	**%CV**	
<0.30	<30	Low variability of dataset around the mean.
0.30-0.42	30-42	Moderate variability of dataset around the mean.
0.42-0.48	42-48	High variability of dataset around the mean.
>0.48	>48	Very high variability of dataset around the mean.

Appendix 5: ANOVA table for plant height at flowering stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	2.587	1.293			
Treatments (varieties)	3	1.047	0.349	0.17	4.76	0.910
Error/Residual	6	11.993	1.999			
Total	11	15.627				

Appendix 6: ANOVA table for plant height at pod filling stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	55.35	27.68			
Treatments (varieties)	3	70.74	23.58	1.95	4.76	0.223
Error/Residual	6	72.47	12.08			
Total	11	198.56				

Appendix 7: ANOVA table for leaf length at flowering stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	6.452	3.226			
Treatments (varieties)	3	13.169	4.390	0.80	4.76	0.537
Error/Residual	6	32.828	5.471			
Total	11	52.449				

Appendix 8: ANOVA table for leaf length at pod filling stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	12.845	6.422			
Treatments (varieties)	3	62.449	20.816	11.33	4.76	0.007
Error/Residual	6	11.028	1.838			
Total	11	86.322				

Appendix 9: ANOVA table for plant biomass at flowering stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	146.17	73.08			
Treatments (varieties)	3	223.33	74.44	2.06	4.76	0.208
Error/Residual	6	217.17	36.19			
Total	11	586.67				

Appendix 10: ANOVA table for plant biomass at pod filling stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	246.17	123.08			
Treatments (varieties)	3	253.67	84.56	4.70	4.76	0.051
Error/Residual	6	107.83	17.97			
Total	11	607.67				

Appendix 11: ANOVA table for root length at flowering stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	7.502	3.751			
Treatments (varieties)	3	13.949	4.650	4.40	4.76	0.058
Error/Residual	6	6.338	1.056			
Total	11	27.789				

Appendix 12: ANOVA table for root length at pod filling stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	9.252	4.626			
Treatments (varieties)	3	8.969	2.990	1.01	4.76	0.451
Error/Residual	6	17.748	2.958			
Total	11	35.963				

Appendix 13: ANOVA table for number of nodules at flowering stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	18.500	9.250			
Treatments (varieties)	3	166.917	55.639	48.85	4.76	<0.001
Error/Residual	6	6.833	1.139			
Total	11	192.250				

Appendix 14: ANOVA table for number of nodules at pod filling stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	26.167	13.083			
Treatments (varieties)	3	744.250	248.083	28.35	4.76	<0.001
Error/Residual	6	52.500	8.750			
Total	11	822.917				

Appendix 15: ANOVA table for small sized nodules at flowering stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	8.667	4.333			
Treatments (varieties)	3	6.250	2.083	1.04	4.76	0.439
Error/Residual	6	12.000	2.000			
Total	11	26.917				

Appendix 16: ANOVA table for small sized at pod filling stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	12.167	6.083			
Treatments (varieties)	3	16.250	5.417	0.67	4.76	0.601
Error/Residual	6	48.500	8.083			
Total	11	76.917				

Appendix 17: ANOVA table for medium sized nodules at flowering stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	12.167	6.083			
Treatments (varieties)	3	58.250	19.417	13.71	4.76	0.004
Error/Residual	6	8.500	1.417			
Total	11	78.917				

Appendix 18: ANOVA table for plant medium sized nodules at pod filling stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	19.50	9.75			
Treatments (varieties)	3	102.92	34.31	2.79	4.76	0.132
Error/Residual	6	73.83	12.31			
Total	11	196.25				

Appendix 19: ANOVA table for large sized nodules at flowering stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	2.1667	1.0833			
Treatments (varieties)	3	38.9167	12.9722	13.34	4.76	0.005
Error/Residual	6	5.8333	0.9722			
Total	11	46.9167				

Appendix 20: ANOVA table for large sized nodules at pod filling stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	0.17	0.08			
Treatments (varieties)	3	296.33	98.78	4.45	4.76	0.057
Error/Residual	6	133.17	22.19			
Total	11	429.67				

Appendix 21: ANOVA table for nodules distributed on tap root at flowering stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	27.9	14.0			
Treatments (varieties)	3	139.8	46.6	0.31	4.76	0.819
Error/Residual	6	908.0	151.3			
Total	11	1075.7				

Appendix 22: ANOVA table for nodules distributed on tap root at pod filling stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	27.32	13.66			
Treatments (varieties)	3	32.75	10.92	0.26	4.76	0.855
Error/Residual	6	256.68	42.78			
Total	11	316.74				

Appendix 23: ANOVA table for nodules distributed on lateral roots at flowering stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	27.9	14.0			
Treatments (varieties)	3	139.8	46.6	0.31	4.76	0.819
Error/Residual	6	908.0	151.3			
Total	11	1075.7				

Appendix 24: ANOVA table for nodules distributed on lateral roots at pod filling stage

Source of variation	Statistical parameters					
	d.f	s.s.	m.s.	v.r (F-stat.)	F-critical$_{(0.05)}$	F pr.
Replication	2	27.31	13.66			
Treatments (varieties)	3	32.75	10.92	0.26	4.76	0.855
Error/Residual	6	256.68	42.78			
Total	11	316.74				