UNIVERSITY FOR DEVELOPMENT STUDIES

DEPARTMENT OF CROP SCIENCE



# EVALUATION OF PEARL MILLET (*Pennisetum glaucum* [L.]) GENOTYPES FOR IMPROVED YIELD, EARLINESS AND TOLERANCE TO DROUGHT IN THE GUINEA SAVANNA AGRO-ECOLOGICAL ZONE OF GHANA

BY

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APRIL 2025

DECLARATION

I, Binzuwan Ekyeaka Koasi, do hereby declare that this work is the result of my work. No previous degree submission or certificate submission has been made here or elsewhere.

However, information relevant to this work from other authors has been cited and duly acknowledged through references.

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

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# ABSTRACT

Global food insecurity predominately affects numerous individuals residing in tropical regions that are either arid or semi-arid. Drought stress is a prime abiotic threat to millet productivity which results in yield loss of about 40 % - 70 %. Ten (10) genotypes of pearl millet comprising five improved varieties (Akad-kom, Afribeh-Naara, Kaanati, 100 Gy, 200 Gy) and five landraces (Tamplimza, Zanyan, Kalaa, Wahab and Naara) were assessed for enhanced agronomic traits. The objective of this study was to identify the traits for high yield, earliness in maturity and drought tolerance. Two field experiments with different planting dates were involved using the same genotypes. The experiments were carried out during the 2023 cropping season from July to December at the Crop Science Department experimental farm of the University for Development Studies (UDS) in Nyankpala in the Guinea savannah agroecology of Ghana. The single–factor experiment was laid out in a Randomized Complete Block Design (RCBD) with four replications in both studies. Parameters related to growth and yield were measured and statistically analyzed using Genstat (18th edition). Results indicated that under suitable conditions, the genotypes Akad-kom, Afribeh–Naara, Kaanati and Naara exhibited the best performance with respect to percentage establishment, days to 50 % flowering, biomass accumulation and grain yield. These genotypes also had early maturing traits. The genotype Akad-kom demonstrated a superior quality among the ten genotypes because it can as well be considered a good source of high-yielding ability. Genotype 200 Gy can be considered high-yielding under suitable environments. Genotypes with high biomass accumulation and grain yield under water – stress included Akad-kom, Naara and Kalaa. They were considered drought-tolerant. Developing desirable traits using these genotypes as the parental lines in plant breeding of pearl millet is recommended for farmers within the Guinea Savanna agro-ecology.

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I also dedicate to my father Mr. Isaac Kaku Aka Binzuwan and my beloved wife.

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## LIST OF ACRONYMS

| | |
|---|---|
| ANOVA | Analysis of Variance |
| CSIR | Council for Scientific and Industrial Research Institute |
| DAP | Days After Planting |
| FAO | Food and Agriculture Organization |
| FAOSTAT | Food and Agriculture Organization Corporate Statistical Database |
| Gy | Gray |
| HI | Harvest Index |
| IAEA | International Atomic Energy Agency |
| LSD | Least Significant Difference |
| MoFA | Ministry of Food and Agriculture |
| RCBD | Randomized Complete Block Design |
| RWC | Relative Water Content |
| ROS | Reactive Oxygen Species |
| SARI | Savannah Agriculture Research Institute |
| WAP | Weeks After Planting |
| WUE | Water Use Efficiency |

# CHAPTER ONE

# INTRODUCTION

## 1.1 Background

Pearl millet (*Pennisetum glaucum* [L.] R. Br., 2n = 2x = 14) is a global food crop extensively produced in Africa and Asia in tropical semi-arid regions (Meena *et al*., 2021). Pearl millet records more than half of global millet production. It is believed that pearl millet occupies about 27 Mha of land to warrant food security for over 90 million people worldwide, the majority of whom are subsistence farmers from Africa and Asia (Shivhare and Lata, 2017).

In the Sub – Saharan Africa, pearl millet is rated as the fourth most significant staple food and recognized as the sixth most important cereal in the world after maize, rice, and sorghum (Faostat, 2015). Pearl millet belongs to the family Gramineae and is mostly propagated by seed. It thrives well in semi-arid to arid zones and is well developed in dry areas with a preferable soil of sandy texture, with low organic matter and nutrient level, and low rainfall (200 – 600 mm) where other cereals such as maize and wheat cannot subsist (Shah *et al*., 2023). This feature of millet facilitates its production in dry areas thus making them crucial to the sustainability of agriculture and food security (Kasei *et al*., 2014).

In 2018, Africa recorded the world's highest millet production with an estimated value of 14 Mt due to area expansion (FAOSTAT, 2018). Africa measures the largest production area occupying approximately 21 Mt ha, then Asia recording 10.9 Mt ha. Among the African continent, West Africa constitutes about 44.3 % of the global millet production area (FAOSTAT, 2018).

Although West Africa is a region considered to have the largest area for pearl millet production, Ghana is exempted from the contributing countries due to the low selected area for pearl millet production.

In Ghana, millet is cultivated predominately in the Upper West, Upper East, and Northern regions owing to its superiority over other commercial crops. The crop is considered a major subsistent one adaptable to their edaphic, climatic environment and low input cultivation conditions (Meena *et al*., 2021). Pearl millet production in the northern part of Ghana covers about 40 % of total arable land under grain cereal cultivation (MOFA, 2019). It is considered a staple food that serves as a stop-gap and a food source to eradicate hunger among many subsistence farmers (Peter *et al*., 2021). Moreover, the C4 photosynthetic mechanism and capacity to resist environmental stress guarantees that it will be considered in a future agriculture system (Meena *et al*., 2021).



### 1.2 Problem statement

Pearl Millet production is mainly centered in developing countries, where average productivity remains below the global average (Sood *et al*., 2019). Over the last few decades, Pearl millet has gained the status of underutilized grain due to the constant decline in global arable land.

This decline is greatly ascribed to a lack of robust crop improvement strategies, geared towards high-value cash - crops and low farm productivity (FAOSTAT, 2018).

Although pearl millet contributes greatly to Ghana's agriculture sector because of a high degree of adaptation to stressful environmental conditions, grain yields are typically low as compared to other main grain crops (Yadav *et al*., 2019). According to FAOSTAT (2016), Ghana's annual millet production is less than 100,000 tonnes, which disqualifies the nation from being considered a major millet-producing country in Africa. Attaining low yield can be attributed to numerous biotic and abiotic stresses encountered in millet production which include low soil fertility, drought, bird damage, and downy mildew disease (Peter *et al*., 2021).

Despite the tremendous potential of pearl millet to outperform in semi-arid environments over cereals, drought stress is the prime abiotic factor that causes substantial yield reduction in pearl millet production in Africa (Gebretsadik *et al*., 2014). This climatic phenomenon does not necessarily provide an optimum environment for millet production. Unlike other abiotic factors, drought or low moisture content generally occurs at the physiological stage of plant growth (Meena *et al*. 2021) and causes a detrimental impact on membrane integrity, osmotic adjustment, water relation, photosynthetic process, and yield output.

The decrease in yield is also ascribed to peasant farmers' continuous utilization of landrace seeds (Sugri *et al*., 2013). Moreover, most developing countries depend largely on indigenous seeds for millet seed supply. As a result, improved seeds are less available, and large-scale cultivation of less productive and heterogeneous landraces or local cultivars is associated with low yield (Rakshit, 2016). In northern Ghana, over 90 % of local farmers rely on their seed banks owing to difficulties in accessing improved seeds and the insufficiency of high-yielding varieties that can substitute the existing landraces (Peter *et al*., 2021), only a small fraction of its germplasm has been exploited to increase its valuable agronomic features, stress tolerance, and productivity, despite possessing a large and diverse germplasm collection and genetic resources (Zhang *et al*., 2016). The qualities of low yield have designated pearl millet as a minor or underutilized grain

According to Meena *et al*. (2021), another potential factor that has led to the decline in millet yield and productivity is the unexplored significant genetic gain through modern plant breeding strategies.

### 1.3 Justification

Over the last five decades, the world's cultivation of millet and its production has remained stationary or decreased when compared to major cereals regardless of the enormous agricultural value they produce. In 2018, it was estimated that the global production of millet has declined drastically accounting for 25.7 % of the total area of land used for agriculture production, and can be linked to the absence of emphasis on crop improvement efforts and other constraints (FAOSTAT, 2018).

Meena *et al*. (2021), stipulated that the sub-standard production of millet is credited to the fact that the momentous genetic gain from modern plant breeding in millets has not yet been recognized. Statistically, the average grain yield produced is approximately 0.5t/ha which is estimated to increase to 3ton/ha with the use of improved varieties and good production management under arid conditions.

According to Peter *et al.* (2021), research focus must be geared towards the breeding of improved varieties to maximize the yield of pearl millets in northern Ghana since varieties with the qualities of early maturity, high yield and resistance to downy mildew disease were preferable traits for pearl millet production among peasant farmers.

Furthermore, the incorporation of economical and sustainable crop management techniques is critical to projecting millet as future gold crops. Planting of early maturing plant species is recognized as one of the significant agronomic management practices that check the high occurrences of disease, parasitic plants, nematodes, insect pests, and weeds that affect millet production (Meena *et al*., 2021). In spite of the trait ability of pearl millet to achieve food security in Africa, it is however the least explored cereal in crop improvements (Dawud *et al*., 2017). The decline in the yield of pearl millet requires deliberate efforts to develop millet varieties with improved desirable traits to facilitate sustainable production.

The development of improved varieties from pearl millet grown as landraces and produced in marginal areas is an important component of breeding technology (Haussmann *et al*., 2012)

It is, therefore, necessary to determine characteristics of high-yielding, earliness and drought-tolerance genotypes to increase its demands.



## 1.4 Objectives

### 1.4.1 Main Objectives

The main objective of this study was to identify desirable agronomic traits of the millet germplasm used in the study.

### 1.4.2 Specific Objectives

Specifically, this study seeks to:

1) Evaluate the genotypes for high – yielding ability
2) Assess the genotypes for earliness in maturity
3) Compare the genotypes for drought tolerance.

# CHAPTER TWO

# LITERATURE REVIEW

## 2.1 Overview

The literature review explains the origin and distribution, ecology of pearl millet, the botany and morphology of pearl millet, soil and climatic adaptation as well as global production and constraints associated with pearl millet. This chapter further describes the nutritional and medicinal value of millet, drought prevalence, screening for drought tolerance and Plant breeding techniques used in pearl millet improvement.

## 2.2 Origin and distribution of millet

Millet is a derivative of the French word "mille" which means a thousand seed grains in a handful (Taylor and Emmambux, 2008). It is stipulated to have been instigated from tropical Central Africa, however, it is extensively distributed throughout India and the drier tropical regions. It was domesticated in the Western state in the 1850s, and the Southeast and Gulf Coast which was established as a minor fodder (Amadou *et al*., 2013). It was acknowledged as a food crop dated 4000 and 5000 BC in the highlands of southern Saharan. Thereafter has gained expansion rapidly over the spheres of Asia and Africa specifically in tropical zones.

Generally, millet is categorized into two main groups. The major millet consists of sorghum [ *Sorghum bicolor* (L.)] and pearl millet [ *Pannisetum glaucum* (L.)] and the minor millet, consist of finger millet [*Eleusine coracan a* (L.) Gaertn.], foxtail millet *[Setaria italica* (L.) Beauv.], proso millet [*Panicum miliaceum* (L.)], kodo millet [*Pas palumscrobi culatum* (L.)], barnyard millet ( *Echinoch loa spp.*), and little millet [ *Panicumsumatrense Roth ex. Roem. and Schult*.] (Meena *et al*., 2021).

Among many countries, the common millet species grown are from the Paniceae tribe and are mostly cultivated for food and fodder (Turbat *et al.*, 2023).

About 20 diverse millet species are cultivated globally. Pearl millet is an extensively grown species in developing countries (Obilana, 2003). Pearl millet (*Pennisetum glaucum* L.R. Br.), finger millet (*Eleusine coracana*), proso millet (*Panicum miliaceum* L.), foxtail millet (Setaria italica L. Beauv.), little millet (Panicum sumatrense), kodo millet (*Paspalum setaceum*) and barnyard millet (*Echinochloa utilis*) are among the species of millet that are often grown. (Figure1) (Bouis, 2000; Wen *et al.*, 2014).

Over 93 countries have contributed significantly to the production of millet worldwide (Obilana, 2003). About 97 % of the millet produced by the least developed nations is consumed by Asia and Africa.

India is recognized as the principal producing country of pearl millet contributing about 26.6 % of the world's production and occupying 86 % cropping area of Asia (Meena *et al.*, 2021).

In Africa, millet production is highly distributed in the semi-arid tropics covering about 18.50 million ha. Four major species of millet are significantly produced in Africa; which include pearl millet, finger millet, tef, and fonio with an average area of 76 %, 19 %, 9 %, and 4 % respectively (Yang *et al*., 2012).

Pearl millet is a momentous staple and resource-based food for deprived farmers in the extremely dry environment of developing countries, particularly in Africa and Asia (Adekunle *et al*., 2013). Again, the world's agricultural system recognizes millets as crucial crops because of their short growing season and pests and disease resistance (Anjali Tiwari *et al*., 2022)

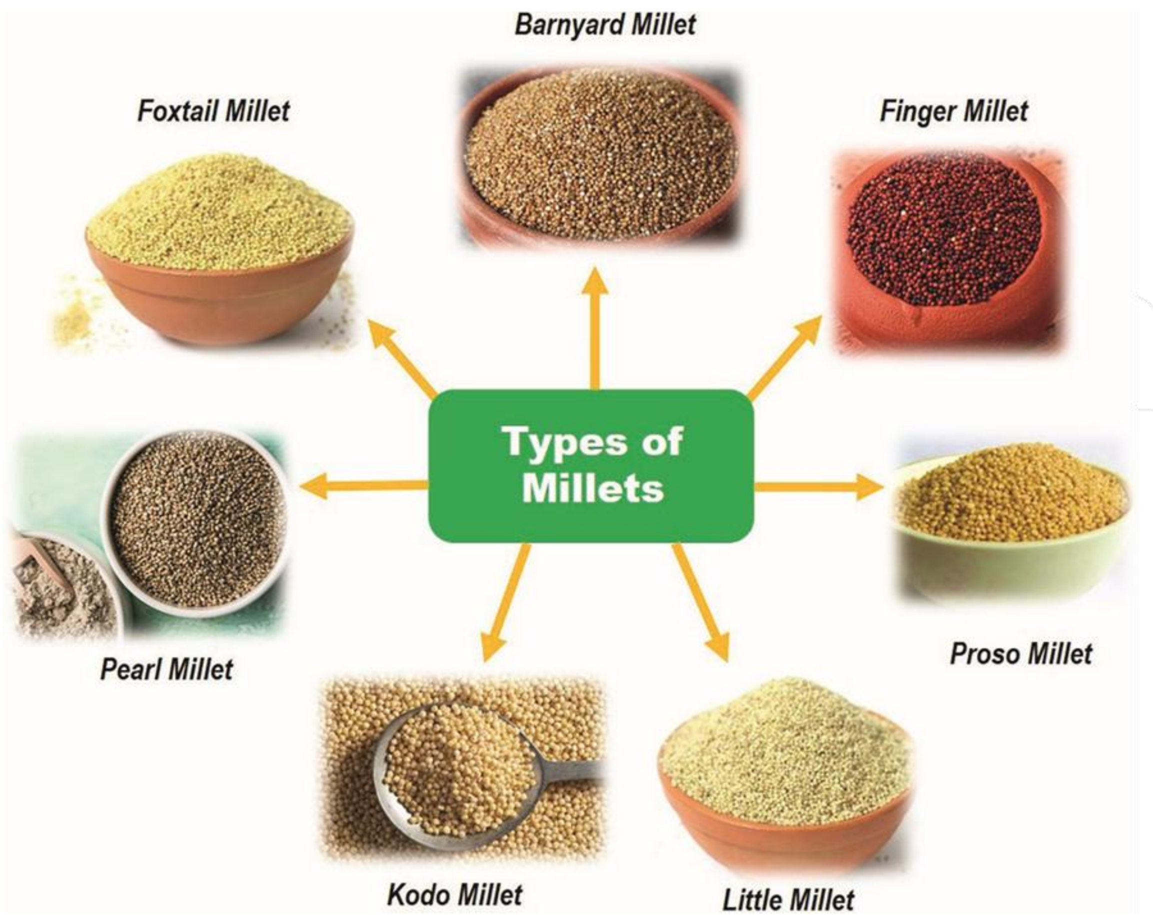


Figure 1: Representation of various types of millets cultivated in the semi-arid regions



### 2.3 Botany and morphology of pearl millet

Pearl millet is a warm–season, C4 annual crop cultivated in the harshest environments among numerous grasses. Its height can increase from 50 cm to 4 m with a cylindrical spike that ranges in length from 15 to 140 cm (Krishna, 2013). Unlike other millet species, pearl millet is characterized by pithy stems and tillers which readily develop into inflorescences with dense panicles. Pearl millet also has long, thin and smooth leaves with hairy surfaces. In an ideal environment, tillers are profusely produced, and their leaves' colour varies from pale yellowish green to deep green. The border of the leaves is finely serrated and has a long tip (Prasad *et al.*, 2020). In pearl millet, the flowering structures are known as panicles or heads which take approximately 40 to 50 days to develop under suitable conditions. A mature panicle assumes a brownish colour. Seed setting begins after fertilization and matures within 25 to 30 days.

Millet grains are tear-shaped to ovoid and exhibit varieties of hues (colours), from creamy white to grey and purple (Prasad *et al*., 2020). The name of the seed originated from its similarity to seed pearls. The average weight of the grain is estimated between 8 and 15 g per 1000 kernels, with a diameter of 1.2 mm to 1.8 mm (Cheick Oumar Kangama, 2021).

The relatively huge germ which makes up about 21 % of the whole grain of pearl millet distinguishes it from other cereals. Again, the endosperm and the pericarp account for 76 % and 10 % respectively of the grain. The typical monocotyledonous root structure of pearl millet consists of fundamental roots, adventitious roots, and collar roots. Fundamental roots begin after 4 days and are effective up to 45 to 60 days, the adventitious root develops from 8 – 12 days until it reaches maturity while the crown or collar root system develops after 30 – 40 days of planting and grows into maturity (Khairwal *et al*., 2007). The pearl millet has a root system that can penetrate the soil with a depth of 180 cm reaching a maximum length of 1500 m per $\mathbf{m^2}$ of the planted region and a mass of 35 g at harvest (Zegada-Lizarazu and Iijima, 2005). At maturity, pearl millet attains a root length of 3 m in sandy soil to catalyze water absorption. The nodes exhibit mild swelling, may have pubescence, and have large spaces between them. At the basal end, there is a ring of adventitious root primordia. The internodal length grows upward from the stem's base. A solitary leaf grows on each node with an alternating arrangement. The axillary bud develops on the node at the bottom of the groove, where it may lay dormant or grow into a tiller at that node (Khairwal *et al*., 2007). Pearl millet can produce numerous efficient tillers that have the potential to increase when grown with wide spacing. Flowering synchronicity, along with a greater number of effective tillers, boosts the prospect of generating a higher seed yield from a single plant.

### 2.3.1 Growth and development of pearl millet

Pearl millet has a diversified range of vegetative, reproductive and physiological properties which significantly contribute to the development of cultivars suitable for different farming systems and climatic conditions (Sharma, 2004). These biological features of pearl millet include growth and development characteristics from germination, seedling and seed formation which are highly efficient for crop improvement (Khairwal *et al.*, 2007). The vegetative phase begins from emergence to the main stem's panicle initiation; the panicle development phase lasts from the main stem's panicle initiation until flowering; and the stage of grain filling, from flowering to the point of physiological maturity. Pearl millet is stipulated to have nine discrete growth stages but concise in the three main growth phases (Prasad *et al*., 2020).

Pearl millet seed germinates in two to three days, at ideal temperatures (25 to 30°C) and moisture levels. Delay in germination largely depends on the variety which lasts for a maximum of five days (Newman *et al.*, 2010). The pearl millet seed swells as a result of absorbing moisture from the damp soil. A tiny sprout called a coleoptile and a main root called a radicle emerge when the seed coat breaks. The juvenile seedlings first consume the endosperm of the seed for nourishment(Khairwal *et al.*, 2007). The plant grows rapidly at 14 days after planting with optimum temperatures which range from 25 ℃ to 35℃

### 2.3.2. Vegetative phase

After planting, pearl millet goes through four primary stages in its vegetative phase, which lasts approximately 21 days. The vegetative phase includes; the emergence stage (2 – 3 days), the three-leaf stage (3 -7 days), the five-leaf stage ( 7 – 14 days) and the panicle initiation stage (14 – 21 days). The radicle exudes from the hilar section upon germination within 16 hours after germination initiation. After 2 hours, the plumule and coleoptile sheath starts to develop. Fine root hairs develop as the radicle quickly grows downwards. Coleoptile gradually rises through the soil until it breaks the surface. Temperature, soil texture, sowing depth, and moisture content all influence the emergence of coleoptiles from the soil's surface within 2 to 3 days under favorable conditions (Khairwal *et al*., 2007).

### 2.3.3 Reproductive phase

The development of an apical structure and a constriction beneath the shoot meristem indicate the translation from the vegetative phase to the reproductive phase, which results in the transformation of leaf primordia to spikelet primordia and the expansion of florets, spikelets, stigmas, glumes and anthers. In pearl millet, the female reproductive organ first emerges before the male reproductive which is known as protogynous. The time interval from panicle commencement to anthesis is crucial in determining the number of grain formations (Khairwal *et al*., 2007). Panicle initiation occurs between 35 and 70 days after sowing which largely depends on the traits of genotype. Panicle development stems from the peduncle's lengthening and the inter-node beneath, in addition to the boot or flag leaf presence, which are indicators of panicle emergence. After six days, the panicle emerges from the leaf sheath and attains full emergence after 4 to 5 days.

The panicle or compound terminal spike of pearl millet has a circumference of 7-9 cm and a length of 20 -25 cm. The two most prevalent forms of panicles are cylindrical or conical, however, there are many variations in their morphologies.

### 2.3.4 Grain-filling phase

This growth stage generally starts with the fertilization of the panicle’s florets and continues until maturity.

The morphology of pearl millet seeds, which are caryopsis seeds, varies greatly, ranging from globular to conical. Again, the colour of the seed is mostly light to deep grey, however, the colour varies from ivory to purplish black. A tiny embryo emerges from the recessed surface toward the narrowing end of the seed. The location of the grain within the panicle determines its size; the grain is greatest at the bottom, intermediate in the center, and smallest at the apex. Grain sizes vary throughout types, typically falling between 4 and 12 g per 1000 grains (Khairwal *et al*., 2007). The degree of grain development determines both seed viability and seeding vigour. A higher proportion of seed setting and bigger seed size in a variety may translate into higher yields. The temperature throughout development had an impact on the vigour of the seed but not on its viability. The majority of the plant's dry weight gain during this time occurs in the grain. The senescence of old leaves continues while flag leaves remain green at the end of this phase. The hilar region of the grain will grow a thin dark layer of tissue, indicating physiological maturity (Prasad *et al*., 2020).



## 2.4 Soil and climate requirements

The biological traits, soil composition and climatic conditions significantly influence the growing season of any crop under production (Turbat *et al*., 2023). Pearl millet outperforms other profitable crops in agriculture resulting from their capacity to conform to marginal and low-input cultivation. Furthermore, the C4 photosynthetic mechanism and resistance to environmental stress make them an apt choice for imminent agricultural systems (Meena *et al*., 2021). It thrives well in environments characterized by low – fertility such as India West Africa, and the Sub-Sahara Desert, where the typical annual precipitation is less than 500 millimeters, and the soil composition is sand–based and somewhat acidic with low organic matter (Habiyaremye *et al*., 2017). Pearl millet is noted for its resilience to climate change and also requires minimal inputs during production in arid regions where other cereals may record low yields due to its nutrients and water usage (Amadou *et al*., 2013). Although pearl millet is thought to be a drought-resistant grain and has a high survival rate in low-pH environments, it cannot withstand standing water (D. Lee *et al*., 2012). A minimum annual precipitation of 400-600 mm and soil temperature of 55℃ is efficient for pearl millet cultivation (Hannaway and Larson, 2004). High temperature in the arid and semi-arid regions is a result of scarce rainfall and solar radiation though pearl millet is accommodative to this environment. The ideal temperature for maximum growth is between 22 to 35 ℃ but differs with varieties (Prasad *et al*., 2020).



Open-pollinated crop like pearl millet generally exhibits a high level of heterosis which facilitates its adaptation to seasonal climatic variability, ensuing from numerous stresses (Jat *et al*., 2012). In terms of fertility requirements, pearl millet doesn't have high nutritional requirements, however, responds to improved soil fertility for maximum production. Its fertility rate is comparable to that of sorghum though the nitrogen requirement is less than sorghum (Sharma *et al.*, 2016). Research affirms that the most limiting nutrient composition for the production of pearl millet in West Africa is phosphorus and nitrogen, but, yield responses to phosphate and nitrogen treatments are widespread, but fertilizer utilization is extremely low due to limited supply (Mason *et al*., 2015).

The account of Khairwal *et al*. (2007) states that an optimum dose of 60 - 80 kg/ha nitrogen application is essential for maximum yield. Additionally, the application of nitrogen in light soil (sandy loams) may experience leaching with heavy rainfall. Upon recommendation, roughly 50 % of the rate should be applied at seedbed preparation and the outstanding proportion applied as side dressing after 25 days of planting. The availability of phosphorus increases the efficient utilization of nitrogen by plants. Phosphorus nutrient is required by pearl millet at the juvenile seedling stage up to the grain-filling phases. Single Superphosphate with a 16 % nutrient composition accompanied by traces of calcium (19.5%), Sulphur (12.5 %), zinc and magnesium is the highly recommended phosphate fertilizer for pearl millet cultivation.

### 2.5 Economic importance of pearl millets

Approximately 80% of the millet grown worldwide is utilized for food, with the remainder going toward bird seed, stock feed (2%), industrial and local brews, and other applications (15%) (Obilana, 2003). It is recognized as a staple grain grown in semi-arid, drought-prone regions on the Indian subcontinent and in sub-Saharan Africa, especially in tropical and subtropical regions to attain local food security (Wrigley *et al*., 2004). Cultural food and beverages and their technologies cannot be underestimated in many developing countries. In the opinion of Gulia *et al*. (2007), the major pearl millet production countries such United States, Australia, and South America primarily cultivate grains for poultry and bird ration due to their high nutritional value and extensively used as a fodder crop (Sheahan, 2014).

Concerning food products, different traditional delicacies are extracted from pearl millet grains which include; porridges, noodles, and snacks. In developed nations, millet grains are also used to make a variety of local and commercial beverages. (Taylor, 2019). In Africa, pearl millet is stipulated to provide about 13.40 kg/yr caloric per food product. The flour and malts of millet are used to make a variety of traditional foods and beverages because the nutritional content is preferable to that of other cereals. Millets contain substantial quantities of protein (teff and fonio can contain approximately 9.5 g/100 g), calcium, ash (finger millet can contain an amount of 344 mg/100 g), potassium, phosphorus (finger millet can make up to 250 mg/100 g iron and 314 mg/100 g, zinc). The millets grains are an imperative source of nutrition for humans and other monogastric animals due to their high methionine levels and good digestion (Obilana, 2003). Millet continues to hold significant socioeconomic value for subsistence farmers in semiarid tropical parts of Africa (Gull *et al*., 2014).

In Ghana, the bulk of pearl millet is produced in the northern regions and is documented as a traditional staple food for sustainable food security. Traditional food products include; "Tuo – Zafi, "Maasa" (fried cakes), and porridge in households. A local beverage made from millet grain is popularly known as "Zimkom" in northern Ghana (Peter *et al*., 2021). The long-season, late-maturing pearl millet varieties' stalks are utilized for firewood, fencing, and roofing materials.



Pearl millet is a high-energy food product which is highly consumed due to the gluten-free component it possesses. Compared to wheat, its protein has a higher biological value. Grain is higher in protein and calories than sorghum or maize, and has a balanced amino acid profile. Grains also lack tannin and contain 5-7% oil (Rai *et al*., 2008).

**2.6 Nutrition and medicinal composition of pearl millet**

Pearl millet is an important food crop desired to attain dietary stability in semi-arid regions and most deprived countries. The nutritional composition outshines other key cereals in terms of their health advantages and nutritional value. Nutrient composition in millets includes oligosaccharides, resistant starch, lipids, antioxidants such as phenolic acids, avenanthramides, flavonoids, phytosterols and lignans which are accountable for major health benefits as shown in Table 1 (Miller, 2001; Edge *et al*., 2005). Also, pearl millet is characterized by bioactive flavonoids and a balanced micronutrient profile with varied pharmaceutical applications (Sood *et al.,* 2019). Statically, pearl millet has exponentially increased global export and import by 155.26 and 127.60 million US$, respectively to enormous health benefits (FAOSTAT, 2018). Pearl millet also has nutraceutical properties and contains about 5 – 6 % of oil. It is generally considered a good source of energy (361 kcal/100g) comparable to other cereals such as rice (345Kcal/100g), maize (125 Kcal/100g), wheat (346 Kcal/100g), and sorghum (349Kcal/100g) and possesses a high level of micronutrients which include zinc vitamins and iron (Kumar *et al*., 2016). The nutrition and medicinal profile of pearl millet is mostly recommended for diabetes or celiac patients due to its significance of being gluten-free cereal with a minimal glycemic index (Malik, 2015). Millets have a defensive mechanism against degenerative illnesses that develop with ageing. Millet can potentially improve the digestive system, boost respiratory health organs, reduce the risk of cancer, detoxify the body, increase muscular and neural systems, and is endowed with high antioxidants (Manach *et al*., 2005; Chandrasekara and Shahidi, 2012).

Despite the numerous nutritional and medicinal benefits endowed with pearl millet, other nutrient components oppose the utilization of millet grain as a nutrient value crop. Goitrogens, oxalic acid, and phytic acid are the three main anti-nutrients found in pearl millet. A concentration of 0.7 – 0.8 % phytate is responsible for the reduction of bioavailability of minerals like zinc, iron, and calcium through a binding process (Lestienne *et al.*, 2007). The metabolites of phenolic flavonoids, C – glycosyl flavones are the major goitrogenic substances which contribute off – odours in pearl millet flour with signs of "mousy" or mouse–dropping flavour (Pelembe, 2001).

**Table 1:Pearl millet nutrition composition**

| Nutrients | Amount( gram) |
|---|---|
| Basic Components | |
| Proteins | 22 g |
| Water | 17.3 g |
| Ash | 6.5 |
| Calories | |
| Total Calories | 756 |
| Calories From Carbohydrates | 600 |
| Calories From Fats | 71 |
| Calories From Proteins | 85.3 |
| Carbohydrates | |
| Total Carbohydrates | 146 |
| Dietary Fiber | 17 g |
| Fat and Fatty Acids | |
| Total Fat | 8.4 g |
| Saturated Fat | 1.4 g |
| Monounsaturated Fat | 1.5 g |
| Polyunsaturated Fat | 4.3 g |
| Omega-3 Fatty Acids | 236 mg |
| Omega-6 Fatty Acids | 4 g |
| Vitamins | |
| Vitamin E | 100 mcg |
| Vitamin K | 1.8 mcg |
| | |
| Thiamine | |
| Riboflavin | 580 mcg |
| Niacin | 9.4 mg |
| Vitamin B6 | 768 mcg |
| Foliate | 170 mcg |
| Pantothenic Acid | 1.7 mg |
| Minerals | |
| Calcium | 16 mg |
| Iron | 6 mg |
| Magnesium | 228 mg |
| Phosphorus | 570 mg |
| Potassium | 390 mg |
| Sodium | 10 mg |
| Zinc | 3.4 mg |
| Copper | 1.5 mg |
| Manganese | 3.3 mg |
| Selenium | 5.4 mcg |

**Source: (Malik, 2015)**

### 2.7 Pearl millet production in Ghana

Africa's contribution to global pearl millet production accounts for about 10.4 million tons of annual grain yield and its estimated land area under production is about 14 million hectares. In West Africa, countries such as Burkina Faso, Chad, Nigeria Niger, Mali, Mauritania and Senegal are recognized as the leading producers of pearl millet (FAOSTAT, 2016). The Upper East, North-East, and Northern regions of Ghana are the primary areas of cultivation for pearl millet in Ghana ranging from local landraces to improved cultivars and hybrids (Peter *et al*., 2021). Again, pearl millet is recognized as a climate-resilient crop and is primarily cultivated in drought-prone environments where other cereals have a low tendency to survive. The overall land area where pearl millet is grown is about 157,000 ha which accounts for 40 % of the total arable lands under cereal cultivation (MOFA, 2019; Anafo *et al*., 2023). In northern Ghana, pearl millet functions as a sustainable food security crop among farmers in marginalized areas. Over 90 % of the people in northern Ghana rely on pearl millet, which is recognized as the third-most significant main food crop (Anafo *et al.*, 2023).

The yield output of pearl millet is equivalent to 1.05 t/ha which is below the annual yield expectancy of 3.1 t/ha (Asungre *et al*., 2015; MOFA, 2017). The low productivity of pearl millet in Ghana can be attributed to inadequate access to high-quality seed and a lack of improved varieties as well as the erratic rainfall pattern among other abiotic stresses (Asungre *et al*., 2021).

To address the issue of low productivity in Ghana, the development of improved varieties has been a keen interest among pearl millet breeders in northern Ghana. Recent development shows that new promising cultivars such as high-yielding, early maturing and tolerance to drought and downy mildew diseases in addition to three more biofortified pearl millet cultivars have been generated to increase pearl millet (Peter *et al*., 2021).

Pearl millet in the long run provides numerous benefits to farmers in Ghana. About 212,827 Mt out of grain yield produced yearly (236,000 Mt) in Ghana is mainly utilized as food in households (MOFA, 2020) Pearl millet stalks can be used for fencing, roofing and fodder, or as a source of saltpetre for preparing traditional foods (Kanton *et al*., 2015).



### 2.8 Global production and constraint of pearl millet

Global production of pearl millet emanates mainly from developing countries with only a small portion originating from the other part of the globe. Asia remains the principal millet production continent evolving from India, China, and Napel (13.2 Mt) followed by Africa (6.9 Mt), Europe (2.3 Mt), America (0.32 Mt), and Oceania (0.03 Mt)

India accounts for 37.5 % of the total world output representing 26.6 % of the global and 83 % of Asia's production area (Sood *et al*., 2019). About 93 countries are contributors to the global production of millet, however, only 7 (India, Sudan, Niger, Burkina Faso, Mali, Chad, Nigeria) countries are significantly producing millet of more than 1 Mha whereas the remaining countries occupy more than 0.1 Mha harvested area (Meena *et al*., 2021). The estimated harvested area for production is 34.1 M ha. India is ranked the highest with a mean area of 15.9 Mha followed by Niger (7.03 Mha), Sudan ( 3.75 Mha ) Nigeria ( 2.7 Mha) Mali ( 2.15 Mha), Burkina Faso (1.39 Mha ), and Chad ( 1.22 Mha ) (FAOSTAT, 2018). According to FAOSTAT (2018), the global cropping area has seen a decline of about 25.7 % from 1961 to 2018. Asia records the largest area of reduction of about 148 %. Africa, most especially West Africa, on the other hand, has experienced an increase in the area of production from 8.8 Mha to 14.3 Mha. Generally, the world millet production has risen by 36 % (575 kg/ha) to (900 kg/ha).

Despite the immense agricultural benefits, pearl millet production is not without constraints. According to Lokur *et al*. (2023), the global Food and Agriculture Organization (FAO) statistics show that millet production has been on an exponential decrease year by year. As of 2019, the production of millet occupied about 718 million hectares, yielding 863 million tons. However, 30.5 million tons were grown globally as of 2020 with 42 % emanating from India, 20 % from Nigeria, 6 % from China 12% from Niger, 5% in Mali, and 3% in Ethiopia.

The majority of these developing countries are faced with the challenge of a seed supply system that is mainly hooked on an informal seed chain. Limited access to improved seeds results in the widespread growth of less productive and diverse indigenous cultivars (Marla, 2016). Unlike Africa, most developed countries such as India and China have a robust market system, well-structured socio-economic conditions as well as better accessibility to improved varieties which are the key factors that contribute to higher productivity. Developing countries are restrained by the adaptability of local cultivars to modern agroecological systems and mechanization which is duly ascribed to an intrinsic challenge such as high decimating and unsynchronized maturity (Meena *et al*., 2021).



Abiotic factors include unreliable rainfall patterns, high temperatures, and high humidity are climatic factors that affect the low productivity of millet in Africa. Edaphic factors include soil type, agronomic practices, and management, soil fertility as well as socioeconomic status of developing countries which greatly influence the millet's efficiency under production (Sood *et al*., 2019). Moreover, a high occurrence of pests, diseases, nematodes, parasitic plants, birds, and weeds are the main biotic restraints to pearl millet production. Millets are generally susceptible to several diseases, including blast (finger millets), downy mildew ( pearl millet and sorghum), grain mould, smut and rust disease (foxtail, teff, and sorghum), ergot ( sorghum and pearl millets and charcoal rot in sorghum (Mishra *et al*., 2017).

In global millet production, weeds infestation accounts for about more than 29 % of the yield productivity reduction and is considered a key biotic stress to pearl millet production



### 2.9 Diseases of pearl millet and their management

The growing interest in pearl millet as a sustainable crop in non-traditional settings has not kept up with the dissemination of precise information on crop diseases. As pearl millet production expands to new regions in temperate and developed countries, the impact of disease-related production constraints is assuming greater significance (Amadou *et al*., 2013).

Millets are known for being resilient in dry climatic environments and, hence have a lower risk of disease infection compared to other crops. Nevertheless, the estimated loss associated with millet grain production is numerous. Fungal infections are more predominant in millet production than in other cereal crops (Das and Rakshit, 2016). Generally, infections caused by fungi like blast rust, downy mildew, and smut can significantly influence pearl millet growth and yield compared to other pathogens (Shivhare and Lata, 2017, Sharma *et al*., 2021).

Pearl millet among other cereals is prone to fungal, bacterial, and viral diseases. Research affirms that about 100 diseases are associated with pearl millet (Satyavathi *et al*. 2021) which is principally caused by viruses, nematodes, fungi, and bacteria, leading to significant reductions in grain yield and quality and, consequently, in grain market value.

Raj *et al*. (2014) discovered that pearl millet is affected by five main diseases of economic importance which include Blast (*Magnoporthe grisea*), downy mildew (*Sclerospora graminicola*), smut (*Moesziomyces penicillariae*), rust (*Puccinia substriata* var. indica), and ergot (*Claviceps* *fusiformis*). The ultimate yield loss caused by these main diseases is between 10 % and 60 %.(Kumar *et al*., 2013).

With increased environmental consciousness, numerous noteworthy and long-lasting strategies have been implemented to combat various plant diseases. (Kumar, 2008). Among these alternatives is the utilization of resistant cultivars, recognized as the utmost suitable and preferred tactic for managing all diseases virtually for all crops. Although a series of strategies are incorporated to equip the immunity to infections and diseases against a wide range of pathogens many insect pest control programs use integrated pest management (IPM) modules. (Satyavathi *et al*., 2021).



## 2.10 Drought prevalence

Insect pests and diseases are the prime biotic factors responsible for substantial yield losses in pearl millet, However, drought stress remains the major abiotic contributor to losses annually in different kinds of millet (Tadele, 2016).

Drought is termed a prolonged period of decrease in moisture content, during which there is prominently less water available than usual for a predetermined time. Water deficit occurs when soil moisture is generally below the requirements for plant development and growth for a specific season. Water–stress prevalence can be estimated according to the phases of drought incident - onset, intensity, spatial coverage, and duration of drought events using the drought index (Eze *et al*., 2020). Drought stress is evident in lack of rainfall or insufficient amount of it, resulting in a decline in agriculture production under rain-fed (Tadele, 2016). Interestingly, Negash *et al.* (2019) and Eze *et al.* (2020) added that the resultant effect of rain-fed agriculture is at risk of impact by drought stress.

Although pearl millet is stipulated to be robust in semi-arid regions which are characterized by extreme climatic and soil conditions, these challenging factors are, however, not the absolute optimum atmosphere for millet cultivation. Drought stress is recognized as a key threat to millet productivity in semi-arid and arid environments which results in yield loss (Mukami *et al*., 2019). Nevertheless, the magnitude of the impact of drought stress varies significantly among various millet types due to the variability of genotypic and phenological traits (Mukami *et al*., 2019). Research affirms that the reduction in growth, yield, osmotic adjustment, pigment and photosynthetic activities are a result of the detrimental effect of drought or inadequate moisture (Ajithkumar and Panneerselvam, 2014).

Water stress in millet can occur both at the pre-flowering or post-flowering stage, and its effects are strongly correlated with the phases of crop growth (Maqsood and Azam Ali, 2007; Mukami *et al*., 2019). Significant yield loss emerges when the flowering stage and grain-filling stages are subjected to severe drought periods (Talwar *et al*., 2020). At the flowering stage, drought stress contributes to yield losses of about 40 % - 70 % in most crops such as pearl millet, finger millet, and teff (Tadele, 2018; Numan *et al*., 2021). Tadele (2016) designated that terminal drought accounts for 60 % yield loss in pearl millet at a reduced moisture content before and during the flowering period. However, the degree of yield loss is reliant on the severity and length of drought as well as the susceptibility of the variety or cultivar (Mukami *et al*., 2019).

In northern Ghana, drought stress due to small rainfall has imposed a significant loss in crop yield due to the susceptibility to climate change and limited adaptative ability (Antwi-Agyei *et al*., 2012). According to Baffour-Ata *et al*. (2021), drought stress has led to the devastation of crops and livestock in northern Ghana resulting in famine over the years and also persistent economic stagnation. Terminal droughts frequently occur in northern Ghana as a result of soil water scarcity ceiling for the duration of the cropping period, which disrupts pearl millet's reproductive growth.

### 2.11 Mechanism for drought tolerance in millet

Millets are considered climate-resilient crops due to their adaptability to various ecological conditions, low susceptibility to environmental stressors, enhanced growth and productivity under low nutrient input conditions, decreased dependency on synthetic fertilizers, and reduced irrigation needs. Nevertheless, the impact of drought stress significantly affects the vegetative and reproductive stages of plants thus reducing their productivity (Tiwari *et al*., 2022).

A wide range of intricate characteristics has been controlled to lessen the effect of droughts on millet yield. In response to drought stress, pearl millet employs three primary techniques: drought tolerance, drought avoidance, and drought escape as a technology for drought tolerance (Fang and Xiong, 2015).

Drought escape is an adaptative mechanism in which the plant attains maturity before drought conditions occur. The mechanism is characterized by rapid growth, early flowering, high leaf nitrogen levels, and high photosynthetic capability, which are characteristics linked to drought resistance (Kooyers, 2015). Research affirms that pearl millet matches its phenology to the mean distribution of rainfall where precipitation is generally scarce and uncertain. The development of the main panicle corresponds with an increasing period of rain thus reducing the the odds of drought events happening before or at the onset of flowering.

Drought avoidance is the ability of a plant to sustain an optimal water balance under moisture stress in order to prevent a water deficit in the plant tissue (Kooyers, 2015). Drought avoidance is characterized by reduced efficiency of water loss through transpiration (e.g., low stomata conductance and reduced leaf) as well as maintaining water uptake during the drought period (e.g. high root-to-shoot ratio) (Tadele, 2016).

Drought tolerance is the ability of a plant to generate some yield despite having a low water potential (Blum, 2005). This event is facilitated by increased osmoprotectants (or suitable solutes like betaines and amino acids) and osmotic adjustment (i.e., lowering osmotic potential by the accumulation of organic and inorganic substances) (Fang and Xiong, 2015).

Kooyers (2015) asserts that the mechanism of drought tolerance is demonstrated by modifications in the phenotypic characteristics of the plant and that the different tactics are interrelated to warrant the adaptation of the plant to the type of drought stress at every stage of its life cycle.

## 2.12 Water use efficiency

Globally, rainfed agriculture contributes about 58 % of the world's food production and occupies 80 % of all agricultural land (Biazin *et al*., 2012). In sub–Saharan Africa rainfed agriculture occupies about 95 % of farmlands. Rainfall remains the principal water supply under rainfed agricultural production in developing countries though it imposes a certain degree of risk and uncertainty (Rockström *et al.*, 2009). Improved agricultural systems can be achieved through efficient and sustainable utilization of natural resources such as rainwater for substantial yield (Gadanakis *et al*., 2015).

Water use efficiency (WUE) is the measure of the volume of water utilized in agricultural productivity in agricultural productivity. Water use efficiency refers to the highest yield productivity per unit of water utilized by the crop (Singh *et al*., 2011). Generally, about 10 – 20 % of accessible water (as rainfall, surface water, or groundwater) is utilized by crops in both rainfed and irrigated agriculture for transpiration. In tropical regions which are noted of scarce water only

5 % of rainfall is well utilized by crops thus a need to improve water usage (Valipour *et al.*, 2015). According to (Zhao et al., 2014), crop drought resilience and output under stress are determined by the efficiency with which water is used, making it a suitable standard in the drought selection process. In contrast to barnyard millet, which is drought resistant, drought tolerance in pearl millet is not demonstrated by increased water absorption efficiency in the uppermost soil layers but rather by a high value of water used (Zegada-Lizarazu and Iijima, 2005). Under extreme drought conditions, pearl millet ranks highest among cereals like sorghum and maize in terms of WUE (Singh and Singh, 1995) due to its efficient water uptake from the underlying soil layer.

WUE appears to function mainly independently in terms of drought tolerance (Passioura and Angus, 2010). Millets with drought tolerance ability may be identified with any of these traits.

### 2.13 Screening for improved millet germplasm

Globally, pearl millet production has been hindered or declined over the past 50 years. This is mostly attributed to the fact that pearl millet has not yet benefited significantly from modern plant breeding advancements (Meena *et al*., 2021). Indigenous cultivars are major origin of genetic diversity for breeding programs in accordance with their ideal genetic composition and agronomic and qualitative features. Accessions of millet species are kept in a few gene banks and databases all over the world. Numerous accessions must be screened to ascertain the essential and desired germplasm and genes for breeding. In this sense, germplasms remain essential to crop development because they provide the necessary variety and form the basis of plant breeding (Maitra *et al*., 2022).

Millet cultivars developed through conventional breeding have successfully been made from millet germplasm, especially for resistance to biotic and abiotic stressors (Vetriventha *et al*., 2020).

According to Mbinda and Masaki (2021), many still undiscovered useful landraces might be sustainably employed to generate superior cultivars that can tolerate environmental changes while maintaining the desired traits. Breeding for superior qualities like high yield, disease and drought resistance requires a genetic approach which involves reproducible screening methods to identify desired traits in germplasm and breeding materials (Tadele, 2016). Submission by Dwivedi *et al*. (2012) affirms that studies on diverse germplasm, which includes landraces, cultivars, and breeding lines that exhibit resilience to biotic stressors, have been identified. Numerous accessions have been identified to be viable sources of green fodder production while other accessions have been identified to have seed yield potentials. Germplasm diversity of any crop is the determinant of successful plant breeding programs (Pattanashetti *et al*., 2016). A suitable screening characteristic for drought stress tolerance ought to satisfy the subsequent requirements: (i) a high degree of heredity, (ii) a substantial correlation with increased grain yield in the target stress environment, and (iii) the expression of tolerance includes an indicator that is simple to measure and has sufficient replication (Ranjith and Rao, 2021).

## 2.14 Plant breeding techniques

Globally, the pearl millet improvement program utilizes genetic resource conservation, evaluation, and modern strategies to overcome biotic and abiotic stress engulfing millet production to increase productivity quality and profitability of the millet yield component (Satyavathi *et al*., 2021). Resistance breeding strategies include effective screening approaches, use of varied germplasm, identifying sources of resistant varieties, understanding resistance genetics, virulence variability, effective breeding and monitoring cultivar performance at the field level to overcome biotic stresses. Diverse breeding procedures, including mutation, recombination/backcross, and modern biotechnological procedures, can help integrate genes for both tolerance and resistance programs as well as produce a variety of interspecific crosses and identify genomic areas for production (Satyavathi *et al*., 2021).

Over the years, convention breeding was recognized as a major technique in improving pearl millet's resilience to both biotic and abiotic stress. However, in recent times, the application of functional genomics and molecular breeding methods has significantly increased pearl millet production under extremely adverse circumstances through the use of cutting-edge genomics techniques and technology even though its impact has not been fully discovered (Shivhare and Lata, 2017). Diversity in genetic traits among landraces provides an optimal potential for breeding cross-pollinated and hybrid variants of pearl millet (Langridge 2005; Varshney and Tuberosa, 2007). The initial stage of pearl millet breeding was geared towards studying the mode of pollination, flowering habit and cytogenetics of the crop which has led to the production of cultivars and inbred lines (Yadav *et al*., 2024).



### 2.15 Conventional breeding

Hybridization is the mating of two parental plants or pure lines that have interesting features, and form the basis of breeding programs. Hybrid breeding has also been used to produce novel cultivars in millet and other crops. Conventional breeding involves the removal of stamen prior to dehiscence of the anthers, and the head is covered with a paper bag to avert self-pollination. The mating process is achieved through the attachment of pollen grains from the male parent to the stigma of the female parent. The paper bag is left over the pollinated head and remains until maturity (El-Hashash and El-Absy, 2019).

The efforts of conventional breeding across selection and hybridization techniques have significantly impacted the breeding of millet cultivars over the years (Jeon *et al*., 2023)

Male sterile-facilitated recurrent selection (MSFRS), diallel selective mating system (DSMS), haploid production, doubled haploids, pure line selection, pedigree selection, bulk selection, mutation, interspecific and intergeneric crosses, backcross, and single seed descent are among the traditional breeding methods (El-Hashash and El-Absy, 2019).

Although certain successes have been attained using traditional breeding methods, the paradigm change in pearl millet breeding requires constant development and application of dynamic, effective, adaptable and modern techniques and resources owing to the drawbacks associated with conventional breeding which include genetic drag and erosion, reproductive obstacles, lacks precision and prolong breeding period thus the need for innovative breeding techniques (Mbinda and Masaki, 2021).



### 2.16 Mutation breeding

For several decades, global agriculture production has benefited greatly from mutation breeding, which is the technique of creating mutant plants with alluring qualities. A mutation is a heritable alteration to genetic material; organisms that exhibit altered traits as a result of these changes are referred to as mutants (Mba, 2013). In the broadest sense, a mutation can be considered any alteration to a single genome's nucleotide sequence (Saitou, 2013). Mutation types are broadly categorized into natural (spontaneous) and artificial (induced) mutation. Plant mutation breeding is a widespread method for enhancing crops because it is an effective tool for identifying biological processes, specific gene functions, and linkages between mutations and phenotypes in the mutant plant (Lee *et al*., 2015). The ultimate cause of evolutionary change is a mutation; new alleles arise in all species, some of which originate naturally and others which are generated by environmental exposure to chemicals and radiation (Naciri and Linder, 2020).

Induced mutations that result in alterations in the amino acid or cis-regulatory element sequences, changing their functional process, have been quite prevalent over the years. Seeds are plant materials that are most often used for induced mutation. Plant materials should be characterized as high-quality, disease-free, homogeneous, and with a high germination rate of 90% or above are essential for breeding (Spencer-Lopes *et al*., 2018). Artificial mutation can be categorized into physical (ionizing radiation, particulate radiation[alpha rays], non – particulate radiation [X-rays, gamma rays] and chemical mutagens (alkylating agent [EMS, MM], base analogues [ 5-chlorouracil], acradine dye) (Spencer-Lopes *et al*., 2018). Drought-tolerant cultivars are among the more than 2000 edit assortments that have been released through mutation breeding (Ahloowalia *et al*., 2004).

Spontaneous mutations on the other hand involve null alleles and alteration in gene expression. This has resulted in significant adjustments in different crop traits to enhance agriculture production, boost product quality, and expand the diversity of goods. For instance, the mutation associated with the tomato SUN gene that causes the elongated phenotype resulted from an integral component of spontaneous mutation. This mutation is characterized by a gene duplication event that is mediated by retrotransposons and involves the relocation of the duplicated gene within the genome under the control of a unique promoter (Xiao *et al*., 2008). The resultant effect of this mutation has led to modern tomato varieties exhibiting an extended fruit shape due to this structural rearrangement. These scenarios highlight the various ways in which mutations enhance genetic diversity and advancement as well as the adaptability of crops. Contributing to significant advancements in agriculture and its by-products.

Although mutation breeding, most especially spontaneous mutation is evident in plant populations through sexual hybridization, the technique is seen to be more realistic and useful for producing hybrids with improved agronomic traits as compared to conventional domestication breeding (Crews and Cattani, 2018).

### 2.17 Molecular markers - assisted breeding

Molecular markers–assisted breeding refers to the application of diverse techniques to modify the DNA to improve traits of interest in plants (Cortés and Du, 2023). Protein markers, DNA markers, and metabolite-based biomarkers are examples of molecular markers; however, only DNA markers are presently used in molecular marker research (Jiang, 2013)

. These approaches are essential to the study of the genetic and molecular processes that focus on crop improvement; these processes include changes in DNA, transcripts, proteins, metabolites, and minerals. Again, molecular marker-assisted breeding facilitates genomic studies where genes of specific traits are identified (Sinha *et al.*, 2023). The application of molecular marker-assisted breeding (MAB) enhances the efficiency and accuracy of plant breeding programs compared to conventional plant breeding (Abdul Aziz and Masmoudi, 2024). The term "marker-assisted breeding" (MAB) refers to a variety of breeding procedures, including genomic selection (GS), genome-wide selection (GWS), marker-assisted backcrossing (MABC), and marker-assisted recurrent selection (MARS) (Ribaut *et al.*, 2010). A fulcrum advancement in the genotypic breeding of crops has erupted the inception of the transgenic breeding program, wherein exact genetic traits and elements of different organisms are infused into plants to have similar features (Caradus, 2023).

### 2.18 Transgenic breeding

With the advent of new biotechnology techniques, current research is geared towards understanding the biotic stresses surrounding pearl millet most especially molecular genetics advancement. Several contemporary genomic tools have increased over the years with the development of high-throughput sequencing platforms. These tools include expressed sequence tags (ESTs), gene expression profiling, molecular markers, genetic transformations and more recently, genome editing, which have been used successfully in a variety of crops to investigate the genetic basis of stress tolerance and development of plants with superior traits (Mbinda and Masaki, 2021).

Plant genetic engineering, which comprises genome editing and genetic transformation, has paved the way for crop modification alternatives to conventional breeding and to address the issue of increased global population, establishing it as one of the most significant and dynamic biotechnological tools to modern agriculture (Mbinda and Masaki, 2021). This technology enables the incorporation of foreign genetic material into distinct plant cells, facilitating the development of transgenic plants with novel, desired traits including drought tolerance, resistance to pests and diseases and quality improvement. Genetic engineering of pearl millet is crucial for enhancing their nutritional quality, and biotic and abiotic stress tolerance. The advancement of crops through biotechnological methods largely relies on effective and efficient plant tissue culture protocols, which can be classified into direct organogenesis, indirect organogenesis and somatic embryogenesis (Loyola-Vargas and Ochoa-Alejo, 2018).

While numerous controversies engulf transgenic breeding programs despite their benefit, researchers are currently, exploring innovative genome editing techniques that alter the genome without creating transgenic plants (Luo *et al*., 2015; Miroshnichenko *et al*., 2019)

**2.19 Biotechnological breeding**

In response to the challenges associated with transgenesis, breeding strategies have transformed through the amalgamation of progressed biotechnological techniques, such as cisgenesis, genome altering, and speed breeding. These progresses have empowered effective breeding by synergistically integrating genotypic and phenotypic characteristics (Sanchez *et al*., 2023). These molecular breeding strategies emphasize recognizing an ideal combination of alleles or haplotypes, gene networks, quality and particular genomic regions for vital breeding with the aim of rapid development of crops with unique traits (Abdul Aziz and Masmoudi, 2024).

Despite the immense benefit of this molecular breeding, limited studies have been conducted on the biotechnological breeding evolution which remains a keen interest for breeders. Scientists are in pursuit of developing this emerging breeding program to enhance agriculture productivity to meet the demands of the growing population, in terms of food security, climate change resilience and changing dietary preferences among consumers (Abdul Aziz and Masmoudi, 2024).

### 2.20 Breeding for drought-tolerance

Genetic probes of variations in flowering time, tillering, grain yield, biochemical analyses, osmolyte analysis, proteome analysis, and gene expression analysis are among the studies on the impact of drought on pearl millet (Shrestha *et al*., 2023). Drought among several stressors causes a significant reduction in growth and yield losses. The primary objectives of breeding are the development of strategies for crops to adapt to several stresses and a variety of approaches have been taken to increase stress tolerance (Calanca, 2017). Reverting to traditional cultivars (Dwivedi *et al*., 2016) as well as wild relatives for valuable stress tolerance alleles is one of the modern plant breeding strategies used to boost stress tolerance (Li *et al*., 2019).

Isayenkov (2019) opined that wild crop progenitors are suitable for the strong foundation for the advancement of novel gene discoveries and physiological adaptation mechanisms. At the inception of domestication of several plant species close traits were selected to determine greater seed size and reduce seed shattering (Meyer and Purugganan, 2013). Identifying genotypes with an intrinsic drought tolerance ability as well as variability in water uptake is of the highest importance for crop yield improvement (Talwar *et al*., 2020). Again, Ranjith and Rao (2021), state that one of the most important priorities in drought research is identifying easily observable morphological and phenological characteristics that indicate the mechanisms and processes that signify drought tolerance.

Over the decades, the identification of qualities contributing to drought adaptation and their value has been useful in different situations using the three major indicators from Passioura's equations (yield = water use efficiency x transpiration efficiency x harvest index) (Passioura and Angus, 2010) although its genotypic traits have been suggested to be potentially significant for drought adaption in many crops including pearl millet. However, the functional element of root system variation and the dynamics of water uptake would be significant in determining how dryland crops like pearl millet performed under drought stress (Vadez *et al*., 2013).

Conventional breeding has immensely added to the development of cultivars with superior adaptation to drought stress which include early maturing varieties that balance water supply and demand before escaping terminal water stress. Furthermore, most field research is substantially hindered by genotype x environment interactions for future progress in breeding types that can withstand water stress (Vadez *et al*., 2013). Plant breeders are typically more interested in using intraspecific variation, which is readily deployable without any genetic obstacles, to improve crop quality at the genetic level. Intra-specific crosses opt for F2 at subsequent generations based on standard Mendelian segregation in order to determine the appropriate plant offspring, including pure lines (Ranjith and Rao, 2021). Alongside in-vitro selection and soma-clonal variants, many breeding strategies, such as mass selection, pure line and recurrent selection, can be used in stressful or non-stressful environments to evaluate drought-tolerant traits. Recurrent selection is predominately employed to improve drought resistance and production capabilities. This breeding technique requires a precise selection after every cycle to boost genetic variety. Research has indicated that the implementation of recurrent selection in drought increases gain yield (Beyene *et al*., 2016; Ranjith and Rao, 2021). Other breeding achievements for drought tolerance traits have been explored through molecular breeding techniques from improved cultivars, landraces and wild-related species (Ranjith and Rao, 2021). In breeding for drought tolerance traits, high-yielding and broad adaptability should be able to coexist in the breeding strategy. The average performance of individual progenies under stress in a variety of environmental circumstances must also be considered to identify this trait as displayed (Table 2)

**Table 2: Characteristics of drought–tolerance traits**

| Categories | Characteristics |
|---|---|
| Morphological and Anatomical: | More Root length, Root Volume, Root Dry Weight, Root Thickness; More Plant Biomass; Yield Harvest index; Delay in flowering Leaf drying; Leaf tip firing. |
| Physiological and Biochemical | Carbon Isotope Discrimination; Osmotic Adjustment Stomatal conductance; Remobilization of stem reserves; ABA; Electrolyte leakage; Specific leaf weight; leaf rolling, tip firing, Stay-green; Epicuticular wax; Heat shock proteins Feedforward response to stress; Cell wall proteins; Leaf water potential; Water use efficiency; Nitrogen use efficiency; Dehydrins; Aquaporins. |
| Phenological: | Late Flowering; Anthesis, Silking Interval; Early to maturity, Weed competitiveness; Seedling vigour; Photosensitivity; perennially. |

**Source: Ranjith and Rao (2021).**

# CHAPTER THREE

# MATERIALS AND METHODS

## 3.1 Background

The field experiments were conducted during the 2023 cropping seasons. The experiments were carried out at the experimental farm of the Department of Crop Science, University for Development Studies (UDS) Nyankpala in the Guinea Savannah agroecology of Ghana during the 2023 cropping season from June to December 2023. Two experiments were conducted. Experiment I was carried out from June to October 2023, while Experiment II was carried out from September to December 2023.

## 3.2 Experimental site

The experiments were conducted in the experimental field of the Crop Science Department at Nyankpala. The site is located 16 km west of Tamale and lies on the latitude 09°24′ 44.4′′ N and longitude 00° 58′ 49.7′′W with an altitude of 183 m above sea level the in Tolon District in the Northern Region of Ghana and lies within the Guinea Savannah agroecology of Ghana (Dzomeku *et al*., 2016). The Guinea Savanna agrological zone experiences an unimodal rainfall pattern with an annual rainfall of 1000 mm to 1200 mm (Lawson *et al*., 2013). Rainfall usually comes slowly in one peak, which starts in April – May and increases exponentially in July – September and declines sharply in October – November. The total precipitation is about 1,500 mm average ambient temperature is high all year round but the harmattan months of December and January are characterized by the minimum temperature that falls to 13℃ at night, while March and April may experience 40℃ in the early afternoon. The textural characterization of the soil is sandy-loam, with moderately drained, capacity contains no hard mass, and is derived from Voltarian categorized as Fluvic lixisol classified as the Nyanpkala series (SARI Annual Report, 2012) with inadequate organic matter deposit due to bush fires and extreme temperatures.

The predominant vegetation type is grassland with few scattered woody perennials such as Baobab (*Adansonia digitata*), shea tree (*Vitllaria paradoxa*), Neem tree (*Azadiracta indica*), Mahogany *(Khaya senegalensis*), Dawadawa tree (*Parkia biglobosa*), and Teak (*Tectonia grandis*). Dominant weeds in the area include Striga weed (*Striga hermonthica*), Broom weed (*Sida acuta*), Spear grass (*Imperata cylindrica*), pig weed *(Boehevia difusa*), and Goat weed (*Andropogon gayanus*) (SARI Annual Report, 2012). Table 3 depicts the experimental site's aerial temperature, relative humidity and rainfall amounts during the experimentation period.

**Table 3:Total rainfall, aerial temperature, and relative humidity during the 2023 cropping season at the experimental site.**

| Month | Total Rainfall (mm) | Temperature Min (°C) | Temperature Max (°C) | Relative Humidity Min(%) | Relative Humidity Max (%) |
|---|---|---|---|---|---|
| January | 0 | 19.99 | 35.91 | 48.61 | 74.77 |
| February | 0 | 24.33 | 37.84 | 36.57 | 59.50 |
| March | 5 | 26.67 | 38.07 | 42.35 | 76.32 |
| April | 126 | 26.39 | 35.79 | 54.70 | 84.30 |
| May | 97.3 | 25.82 | 33.49 | 65.16 | 90.81 |
| June | 107.1 | 24.22 | 32.23 | 67.43 | 90.73 |
| July | 254.3 | 24.22 | 30.49 | 76.32 | 94.65 |
| August | 97 | 23.72 | 29.15 | 81.45 | 95.77 |
| September | 238.1 | 24.11 | 30.13 | 78.57 | 95.00 |
| October | 140.1 | 24.52 | 31.95 | 71.87 | 94.71 |
| November | 13.2 | 24.76 | 34.62 | 59.63 | 90.43 |
| December | 0 | 19.39 | 36.01 | 37.16 | 68.58 |

**Source: CSIR -SARI 2023.**

### 3.2.1 Materials

Ten genotypes comprising five improved and five landraces were used in the study. Three improved genotypes namely; Afribeh - Naara, Akad-kom, and Kaanati, were obtained from the CSIR Savannah Agriculture Research Institute (SARI) of the Council for Scientific and Industrial Research (CSIR) while two mutant genotypes (100Gy and 200Gy) were obtained from the Department of Crop Science, University for Development Studies. The five landraces namely; Tamplimza, Zanyan, Kalaa, Wahab, and Naara were also obtained from farmers in the surrounding communities of Nyankpala in the Northern Region of Ghana.

## 3.3 Experimental design and agronomic practices

The field experiments (Experiment I and II ) were laid out as a single-factor experiment comprising ten treatments (genotype) with four replications in a Randomized Complete Block Design (RCBD). There were ten plots in each replication, each plot measuring 4 m * 4 m (16 $\mathbf{m^2}$) with an alley of 1.0 m between plots. In each experiment, the replications were separated from one another by a 2 m alley. The experimental fields were tilled using a chisel plough and disc harrowed after all vegetation and debris were cleared. A pre-emergence herbicide was applied to the field two weeks after the conventional tillage. The fields were demarcated using garden lines and pegs. Each of the genotypes was sown with a planting distance of 0.75 m * 0.25m. A maximum of five seeds were planted per hole and later thinned to two plants per hole. Empty hills were refilled a week after planting. Manual weeding practices were done every three weeks to reduce competition between weeds and crops. NPK fertilizer was first applied as a basal application and a top dressing to facilitate its growth and development. Fungicide application was imposed on fungi-infected millet.

### 3.4 Experimental Setups

In Experiment I seeds of the ten genotypes mentioned above were planted and the high-yielding but early-maturing ones were selected in a rainfed field experiment. The experiment was conducted from June to October 2023 cropping season.

In another but related study (Experiment II), the ten (10) genotypes comprising five improved varieties namely Afribeh - Naara, Akad-kom, Kaanati, 100 Gy, and 200 Gy and five landraces namely Tamplimza, Zanyan, Kalaa, Wahab and Naara were planted and evaluated for drought tolerance. Seeds of genotypes were planted late so that the growth and development of the plant coincided with the drought period within the season from 2$^{nd}$ September to 10$^{th}$ December 2023

### 3.5 Data Collection

At four weeks after planting (WAP), the following agronomic variables were measured at two-week intervals; Percentage establishment, days to 50% flowering, plant height, number of tillers, number of leaves, leaf area index, and chlorophyll content. In addition, dry matter accumulation, productive tillers, thousand seed weight, total grain yield water use efficiency and harvest index were measured at harvest. Data collected for the various parameters were the same for both experiments with the exception of water use efficiency and harvest index which were collected to ascertain drought tolerance in experiment II. The period's meteorological conditions, including temperature, relative humidity, and rainfall, were also observed.

#### 3.5.1 Percentage establishment

Four weeks after planting emerged seedlings were counted. Means were calculated and used to compute percentage establishments as shown in the equation

$$\text{Percentage establishment} = \frac{\textbf{Number of emerged seedlings}}{\textbf{Total number of seed sown}} \times 100 \quad \ldots\ldots\ldots\ldots\ldots 1$$

### 3.5.2 Days to 50 % flowering

Each genotype was observed closely from the day of sowing to the day half of the plant in each plot flowered. The number of days taken for each genotype to attain 50 % flowering was then recorded from the day of sowing to flowering.

### 3.5.3 Plant Height

The height of the millet was measured at 4, 6, 8, and 10 WAP. The height from the plant's base to the flag leaf's attachment was measured with a meter rule, and their averages were calculated.

### 3.5.4 Number of leaves per plant

The number of leaves was determined by counting the number of leaves of the tagged plants in each plot. Then, their averages were computed and recorded to represent each treatment.

### 3.5.5 Number of Tillers

Tillers were counted from the base of the plant at 4, 6, 8, and 10 weeks after planting (WAP). The mean value was recorded.

### 3.5.6 Leaf Area Index

Data on the leaf area were taken at 4, 6, 8 and 10 weeks after planting (WAP) according to Bréda, (2003). These were obtained by measuring the length and the width of the plant leaf using a meter rule.

The Leaf Area Index was computed by the formula,

Total Leaf Area (TLA) = Leaf length × leaf width…………………………………..2

$$\text{Leaf Area Index (LAI)} = \frac{\mathbf{TLA \times nLv \times constant}}{\mathbf{PD}}$$

Where;

LAI is the Leaf Area Index

TLA is the Total Leaf Area

nLv is the number of Leaves

PD is the planting distance

Constant = 0.68 for millet

### 3.5.7 Chlorophyll Content

With the help of a chlorophyll meter, the chlorophyll content for plants was taken at the $4^{th}$, 6th , $8^{th}$ and $10^{th}$ weeks after planting (WAP). Four plants were randomly selected from each plot, and the chlorophyll contents were taken from four leaves of these five plants. The average chlorophyll content for each plot was then computed and recorded.

### 3.5.8 Head Length

Using a tape measure, the length of the panicles of four tagged plants was measured at harvest after drying to approximately 13 % moisture content. Mean values were recorded in centimeters.

### 3.5.9 Head Girth

The width of the panicles was estimated using a Vernier caliper which was used to compute the panicle average diameter. The girth was measured at harvest after drying to approximately 13 % moisture content.

### 3.5.10 Head weight

At harvest, millet heads were evenly dried and weighed using an electronic scale for their respective dry head weight. Mean values were recorded in grams and computed.

### 3.5.11 Biomass Accumulation

Four plants were chosen at random for each genotype and replications per plot for dry matter accumulation at eight and ten weeks after planting (WAP). At ground level, the roots and shoots were separated to determine the root and shoot dry matter. The total fresh shoot and root weights were measured. The roots and shoot were then kept separate in brown envelopes and oven-dried for 24 hours at 80°C. The root and shoot dry weights of the dried samples were determined by weighing them again.

The dry weights were estimated using the equations suggested by Zeiller et al. (2007).

$$\text{DMY(kg/ha)} = TFW\text{(kg)} \times \frac{\mathbf{1000\ (m^2/ha)}}{\mathbf{H\ (m^2)}}\ \text{X}\ \frac{\mathbf{SDW\ (kg)}}{\mathbf{SFW\ (kg)}} \quad \ldots\ldots\ldots\ldots\ldots 3$$

Where:

DMY is the dry matter yield

TFW is the total fresh weight

SFW is the shoot fresh weight

SDW is the shoot dry-weight

Root-Shoot ratio (dry weight) was also given by:

$$\text{RS} = \frac{\mathbf{RDW}}{\mathbf{SDW}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. 4$$

Where:

RS is the root-shoot ratio

SDW is the shoot dry-weight

RDW is the root dry weight recorded.

### 3.5.12 Thousand Seed weight

Thousand seeds from each plot were counted and weighed using an electronic scale and their results were recorded in grams. Average values were computed

### 3.5.13 Total grain yield.

Grain yield was estimated within 16 $\mathbf{m^2}$ for each experimental unit. Panicles were harvested, dried, and weighed after threshing in kilograms. Total grain yield was extrapolated to kg/ha for each treatment and was determined using the formula

GY (kg/ha) = $\frac{\mathbf{GYM\ (kg)}}{\mathbf{A\ (\ m^2)}}$ x $\mathbf{10000}(\ \mathbf{m^2})$ ……………. 5

Where:

TGY is the final grain yield

GYM is the grain yield from each plot

A is the area from which the plant samples were harvested.

### 3.5.14 Water Use Efficiency and Harvest Index

The Water Use Efficiency (WUE) of individual treatment was calculated for Experiment II using the formula suggested by Zhao *et al*., (2014)

WUE = $\frac{\mathbf{Y}}{\mathbf{TR}}$ ………………….. 6

Where;

WUE = Water use efficiency

Y = Crop Yield (g)

TR = Total rainfall (mm)

The harvest index for each treatment was also determined as follows according to ElBaradei, (2001)

$$\text{Harvest Index (HI)} = \frac{\textbf{Economic yield}}{\textbf{Total Dry matter accumulation}} \ldots\ldots\ldots\ldots\ldots\ldots\ 7$$

**3.6 Statistical analysis**

Descriptive analyses were performed on the quantitative data from the field experiments to determine the mean values, standard error of the means and standard deviation. One-way analysis of variance (ANOVA) was used to determine the statistical differences in the parameters between the various treatment options. At a probability level of 5%, the least significant differences (LSD) were used to compare the means, and the standard error of the means and the Duncan Multiple Range Test were used to separate the means. All data analyses were performed using Microsoft Excel and GENSTAT 18 Statistical package. Results were presented in tables and graphs

# CHAPTER FOUR

# RESULTS

## 4.1 Results for Experiment I

### 4.1.1 Percentage establishment

Genotypes recorded increases in the establishment. At 4 weeks after planting (WAP), values were highly significant ($P < 0.001$), with Akad-kom recording the highest establishment of 75 %, while the genotype Naara recorded the least establishment of 31 % (Figure 2). All other genotypes were statistically similar.

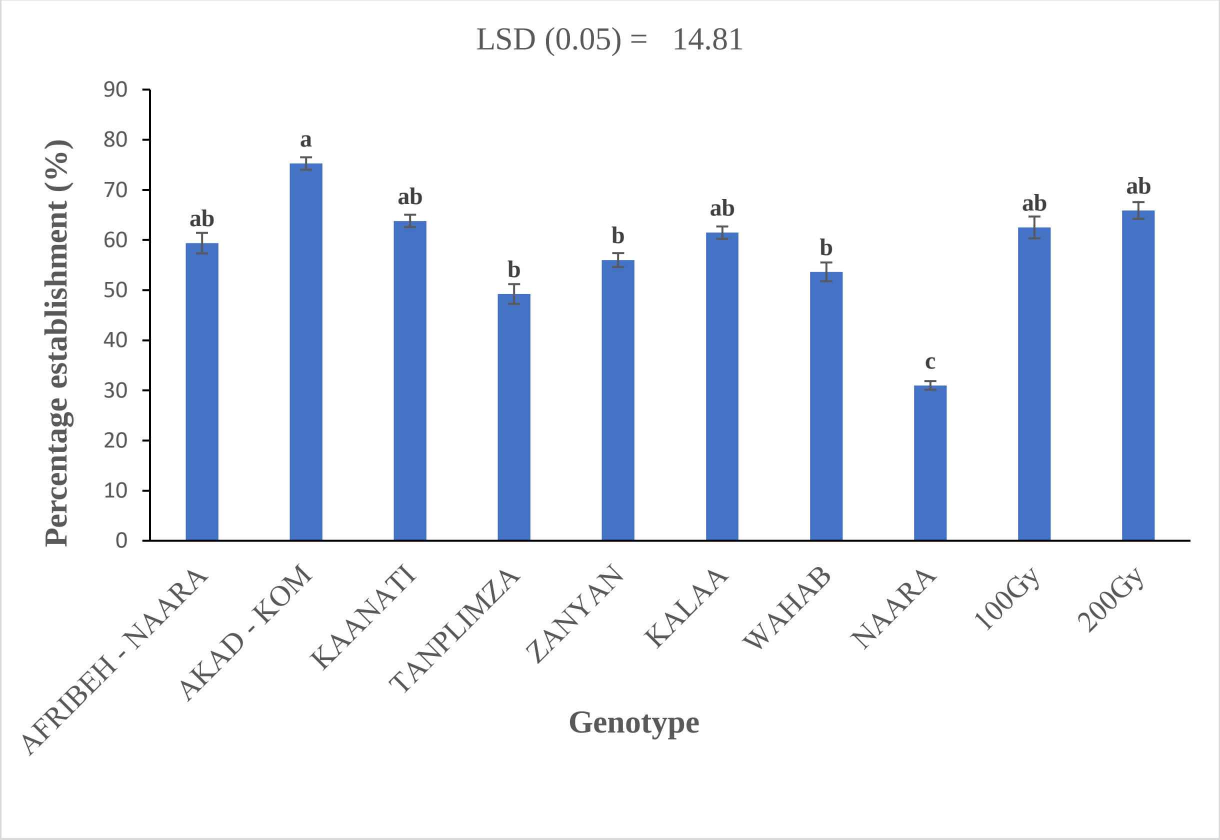


**Figure 2:Effects of genotypes on percentage establishment of millet. Data were obtained from experiment I. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability**

### 4.1.2 Days to 50 % flowering

Genotypes showed highly significant (P < 0.001) differences on days to 50 % flowering of pearl millet. Days to 50 % flowering recorded on the various genotypes varied from 47 to 107 days. Tanplimza recorded the highest number of days to 50 % flowering (107 days) followed by Zanyan recording 98 days to 50 % flowering (Figure 3), while Afribeh-Naara recorded the lower value for days to 50 % flowering (47 days).

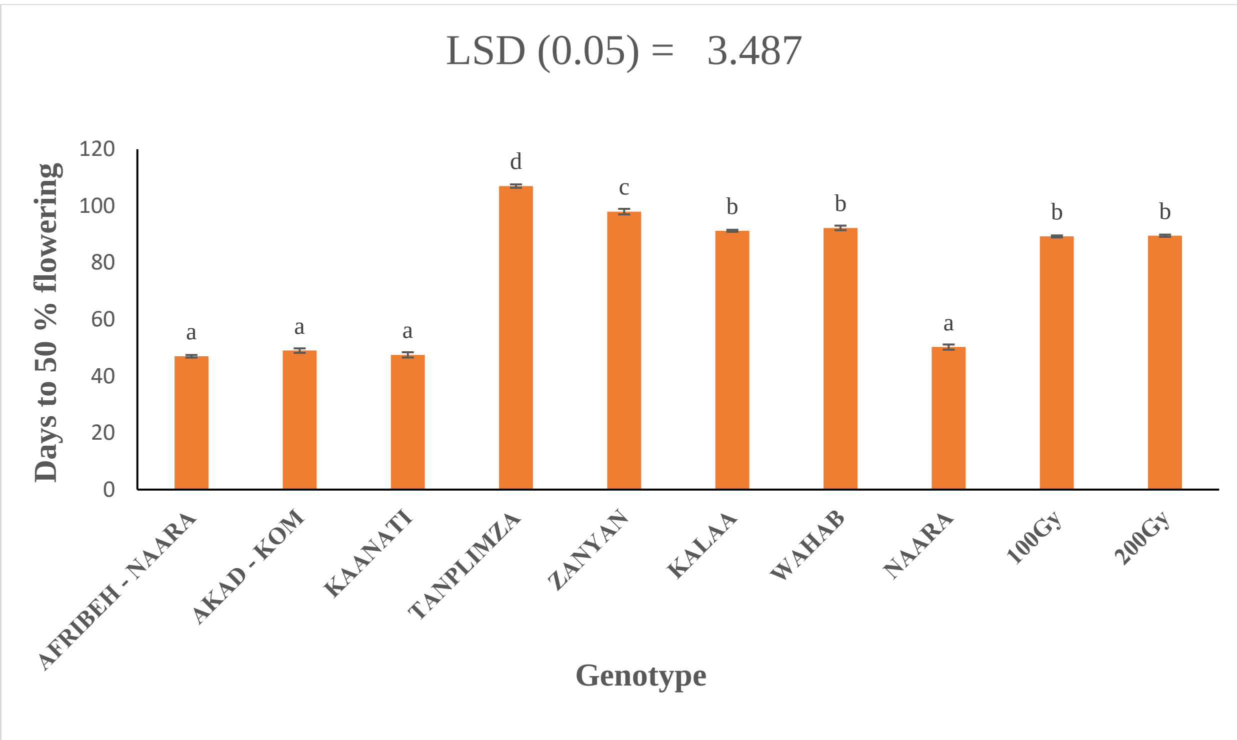


**Figure 3: Effects of genotypes on days to 50 % flowering of millet. Data were obtained from experiment I. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability**

### 4.1.3 Number of tillers

The tiller count was highly significantly (P > 0.001) different among the genotypes during the various data collection weeks. At week 4 and week 6, Tanplimza recorded the highest number of tillers with a mean value of 6 and 12.5 respectively (Table 4). Kalaa, Wahab, and the mutant genotypes were not statistically different from Tanplimza at both weeks. At 8WAP and 10WAP, the same trend was observed among the genotypes however, Wahab exhibited superiority over the remaining genotypes for the number of tillers. The pearl millet varieties Akad-kom, Afribeh–Naara, Kaanati, and Naara were significantly different from the other genotypes throughout the weeks recording the least number of tillers.

**Table 4: Effects of genotypes on number of tillers of millet.**

| Genotype | Weeks After Planting (WAP) | | | |
|---|---|---|---|---|
| | 4 | 6 | 8 | 10 |
| Afribeh - Naara | 2 | 5 | 5 | 7 |
| Akad-kom | 2 | 5 | 7 | 7 |
| Kaanati | 1 | 4 | 4 | 5 |
| Tanplimza | 6 | 13 | 16 | 21 |
| Zanyan | 6 | 12 | 17 | 21 |
| Kalaa | 6 | 12 | 18 | 21 |
| Wahab | 6 | 13 | 19 | 23 |
| Naara | 2 | 6 | 6 | 7 |
| 100Gy | 6 | 13 | 17 | 22 |
| 200Gy | 5 | 13 | 17 | 19 |
| LSD(0.05) | 1.409 | 3.18 | 4.198 | 5.263 |

**Data were obtained from experiment I in the rainy season of the year 2023**

### 4.1.4 Plant Height

At 4 WAP, plant height varied highly significantly (P < 0.001) among the genotypes. Kaanati and Afribeh–Naara recorded the highest height with mean values of 20.5 cm and 19 cm respectively. Both Kalaa and Naara produced the least heights with mean values of 13.25 each. The same observations were made in week 6. Again, at 10 WAP, 200 Gy gave the highest height followed by Afribeh – Naara with a mean heights of 172 cm and 151 cm respectively while Zanyan recorded the reduced plant height (Figure 4).

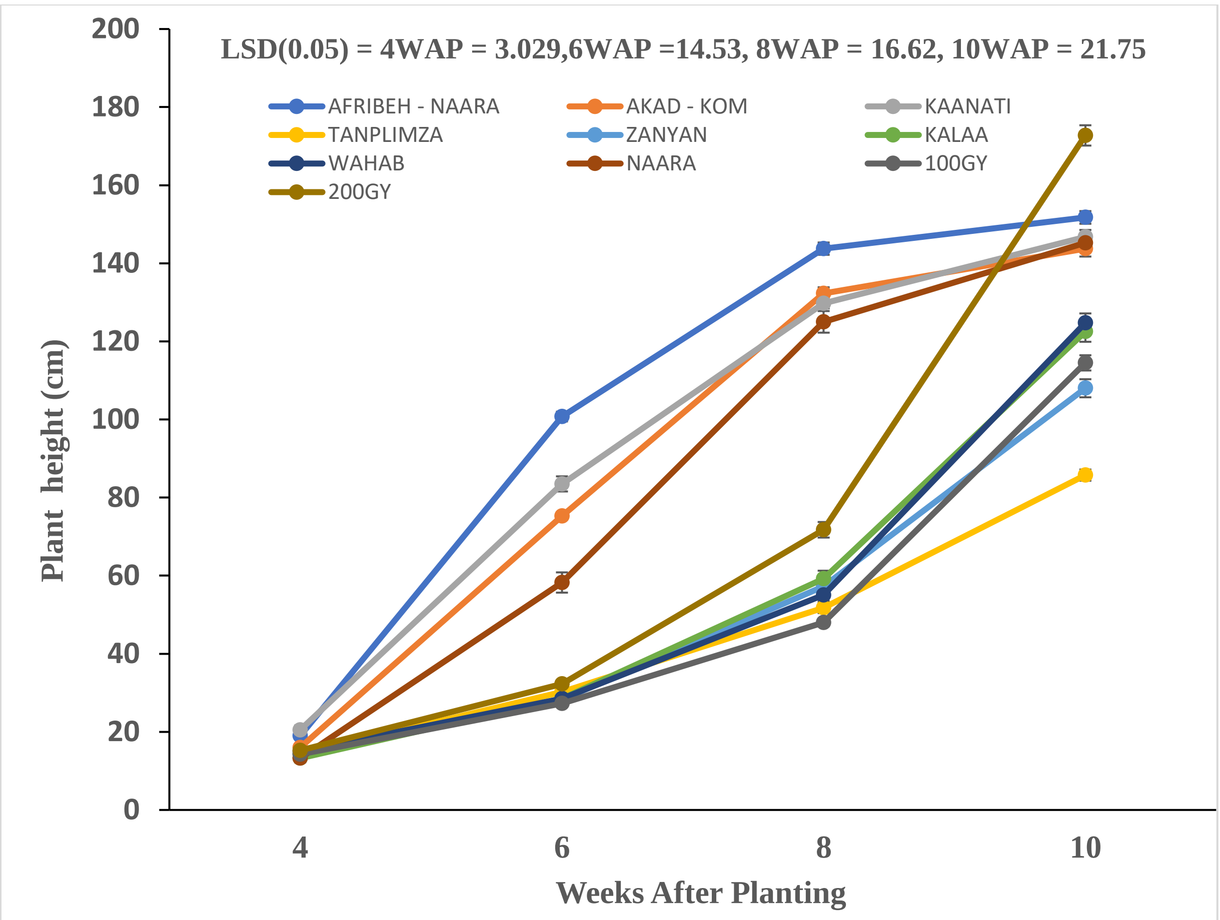


**Figure 4: Effects of genotypes on plant height of millet. Data were obtained from experiment I . Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability**

### 4.1.5 Number of Leaves

Genotypes varied highly significantly (P < 0.001) for the number of leaves produced as shown in Table 5.

At 4 WAP and 8 WAP, 200Gy recorded the highest number of leaves with mean values of 6 and 9 respectively. This was followed by Zanyan and Wahab with average values of 5 and 9 respectively for each of the weeks. Akad-kom recorded the least number of leaves at both 4 and 8 WAP with average values of 5 and 7 respectively. Similarly, at 10WAP 200Gy, Zanyan and Wahab recorded the highest number of leaves with a mean value of 11 while Afribeh – Naara, Akad-kom, Kaanati and Naara recorded the least with a mean value of 8.

**Table 5:Effects of genotypes on number of leaves of millet.**

| Genotype | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | 4 | 8 | 10 |
| Afribeh - Naara | 5 | 8 | 8 |
| Akad-kom | 5 | 7 | 8 |
| Kaanati | 6 | 7 | 8 |
| Tanplimza | 5 | 8 | 10 |
| Zanyan | 5 | 9 | 11 |
| Kalaa | 5 | 8 | 10 |
| Wahab | 5 | 9 | 11 |
| Naara | 6 | 7 | 8 |
| 100Gy | 5 | 8 | 10 |
| 200Gy | 6 | 9 | 11 |
| LSD(0.05) | 0.513 | 0.7334 | 0.1045 |

**Data were obtained from experiment I in the rainy season of the year 2023**

### 4.1.6 Chlorophyll Content

Table 6 revealed that the various genotypes significantly ($P < 0.001$) varied for Chlorophyll content at all weeks. At 4WAP and 6WAP, Kaanati recorded the highest chlorophyll content with an average value of 41.95 and 51.08 spad units respectively whereas Tanplimza, Wahab and Zanyan at both weeks recorded the lowest chlorophyll content with mean values of 33 and 37 spad units respectively. Again, at 8WAP and 10 WAP, Kaanati obtained the highest chlorophyll content with mean values of 57.70 and 63.20 spad units while Wahab and Zanyan recorded the least chlorophyll content at 8 WAP with a mean value of 42 spad units. Wahab recorded the least chlorophyll content at 10 WAP with a mean value of 45.63 spad units.

**Table 6: Effects of genotypes on chlorophyll content.**

| Genotype | Weeks After Planting (WAP) | | | |
|---|---|---|---|---|
| | 4 | 6 | 8 | 10 |
| Afribeh - Naara | 36.88 | 46.20 | 54.30 | 60.53 |
| Akad-kom | 33.18 | 43.40 | 52.13 | 60.93 |
| Kaanati | 41.95 | 51.08 | 57.70 | 63.23 |
| Tanplimza | 33.23 | 36.95 | 42.73 | 48.78 |
| Zanyan | 32.73 | 37.48 | 41.80 | 47.25 |
| Kalaa | 34.60 | 39.18 | 43.15 | 48.78 |
| Wahab | 33.30 | 36.55 | 41.90 | 45.63 |
| Naara | 32.98 | 45.25 | 54.60 | 63.20 |
| 100Gy | 32.48 | 38.08 | 42.53 | 48.18 |
| 200Gy | 35.20 | 40.03 | 43.80 | 48.45 |
| LSD(0.05) | 3.14 | 2.75 | 4.88 | 4.52 |

**Data were obtained from experiment I in the rainy season of the year 2023**

### 4.1.7 Leaf Area Index

Genotypes varied highly significantly ($P < 0.001$) for leaf area indices at 4, 8 and 10 weeks after planting. At 4WAP, Afribeh–Naara recorded the highest Leaf area index followed by Kaanati with mean values of 0.24 and 0.23 respectively while Wahab recorded the lowest leaf area index of 0.10. However, at 8WAP 200Gy recorded the greatest leaf area index followed by Wahab while Akad-kom and Tanplimza recorded the lowest leaf area index. Again, 200Gy obtained the highest leaf area index while Afribeh–Naara recorded the lowest area index at 10 WAP (Table 7).

**Table 7 :Effects of genotypes on leaf area index of millet.**

| Genotype | Weeks After Planting | | |
|---|---|---|---|
| | 4 | 8 | 10 |
| Afribeh - Naara | 0.237 | 0.675 | 0.869 |
| Akad - Kom | 0.181 | 0.639 | 0.910 |
| Kaanati | 0.225 | 0.649 | 0.867 |
| Tanplimza | 0.106 | 0.638 | 1.107 |
| Zanyan | 0.133 | 0.778 | 1.400 |
| Kalaa | 0.106 | 0.656 | 1.122 |
| Wahab | 0.105 | 0.812 | 1.205 |
| Naara | 0.140 | 0.651 | 1.019 |
| 100Gy | 0.107 | 0.761 | 1.160 |
| 200Gy | 0.144 | 1.063 | 1.706 |
| LSD(0.05) | 0.054 | 0.195 | 0.277 |

**Data were obtained from experiment I in the rainy season of the year 2023**

### 4.1.7 Biomass Accumulation

The dry weight of genotypes were highly significantly different (P < 0.001). At harvest, Zanyan recorded the highest dry matter content with a mean value of 1.09 kg (Figure 5). The were no significant differences among the remaining genotypes for their dry matter content with a mean value ranging from 0.43 kg to 0.60 kg.

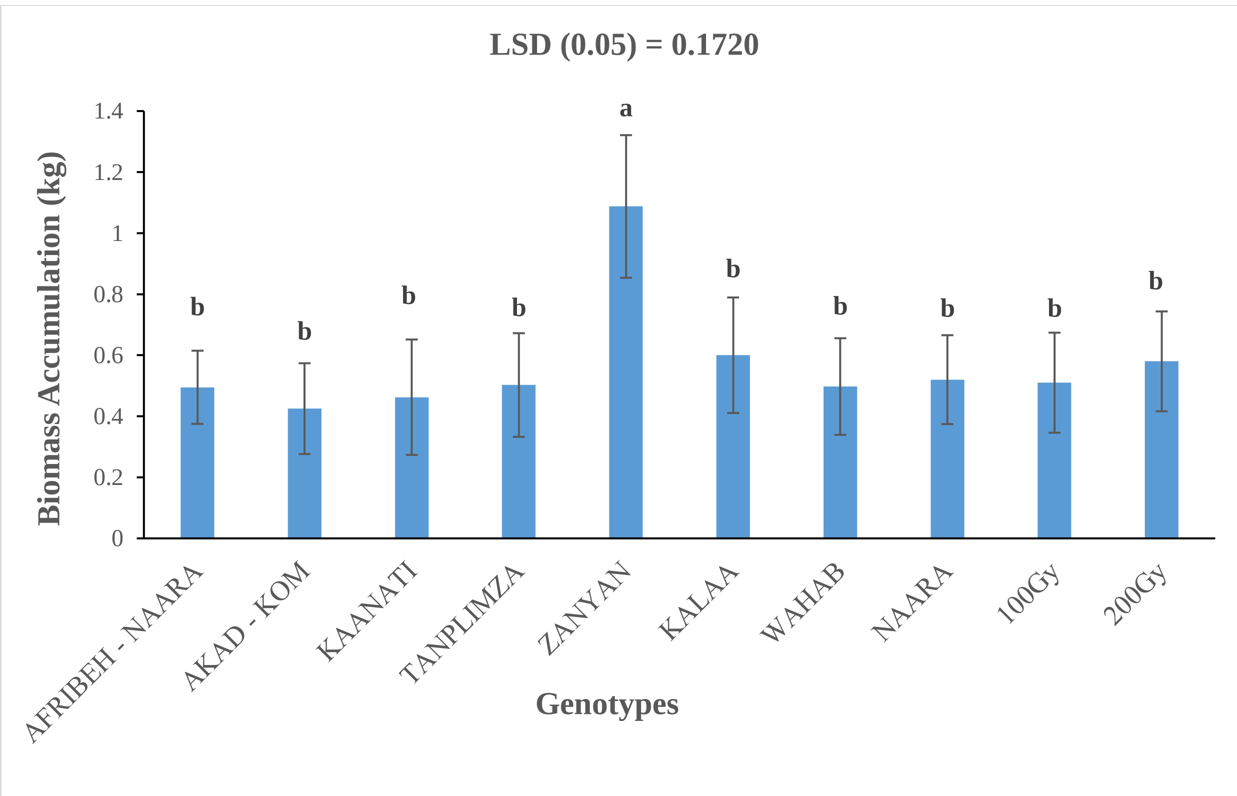


**Figure 5: Effects of genotypes on biomass accumulation of millet. Data were obtained from experiment I. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability**

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### 4.1.9 Thousand Seed Weight

Also, thousand seed weight highly significantly varied (P > 0.001) among the various genotypes. The highest seed weight was obtained by the genotype Naara with a mean weight of 19.5 g followed by Afribeh -Naara with a mean weight of 16.6 g. The 100 Gy genotype recorded the least seed weight with a mean value of 10.55g. The were no significant differences among the remaining genotypes (Figure 6).

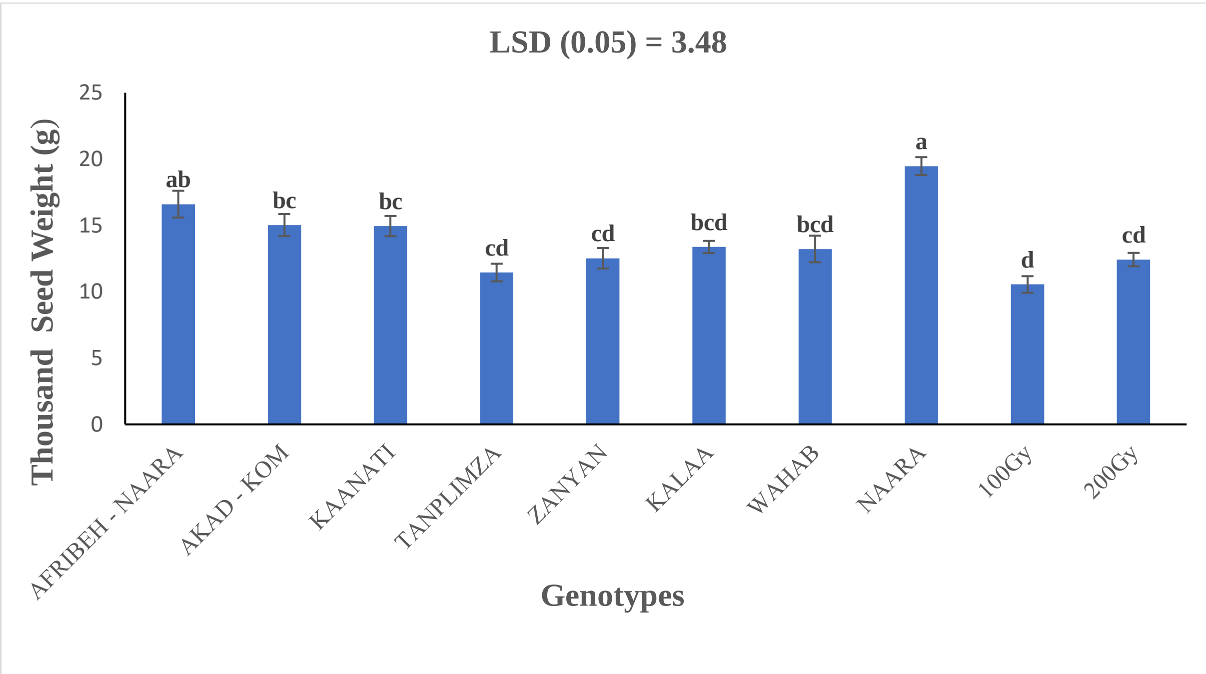


**Figure 6: Effects of genotypes on thousand seed weight of millet. Data were obtained from experiment I. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability.**

### 4.1.9 Head Length

At harvest, data collected on head length highly significantly (P > 0.001) varied among the various genotypes (Figure 7). Kaanati recorded the highest length of 26.67 cm while Akad-kom followed by Naara recorded the lowest length with a mean value of 13.97 cm and 20.35 cm respectively. All the other genotypes showed statistical indifference to each other with a mean value of 24.75 cm

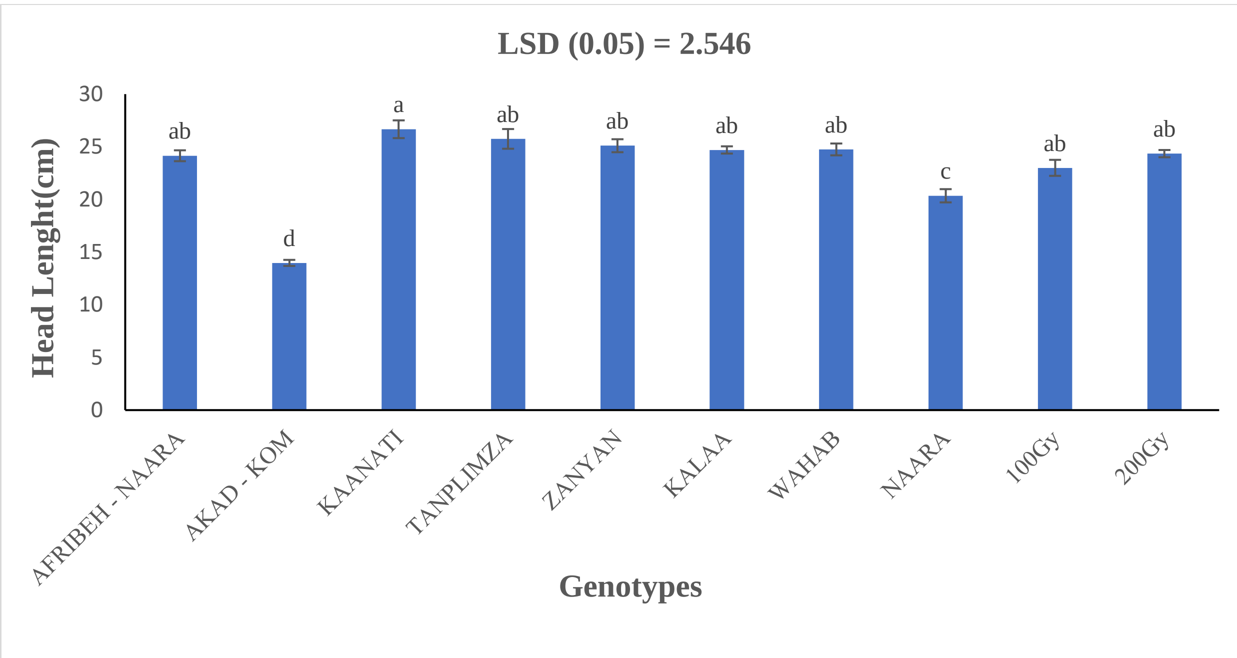


**Figure 7 Effects of genotypes on head length of millet. Data were obtained from experiment I. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability.**

### 4.1.10 Head Girth (Width)

Figure 8 display a highly significant (P > 0.001) variation for head girth which is influenced by the various types of genotypes. The genotype Akad-kom gave the highest head width with an average value of 3.45 cm followed by 100Gy, Zanyan, and Wahab. Afribeh–Naara and Kaanati both recorded the lowest head width with a mean value of 2.27 cm and 2.07 cm respectively.

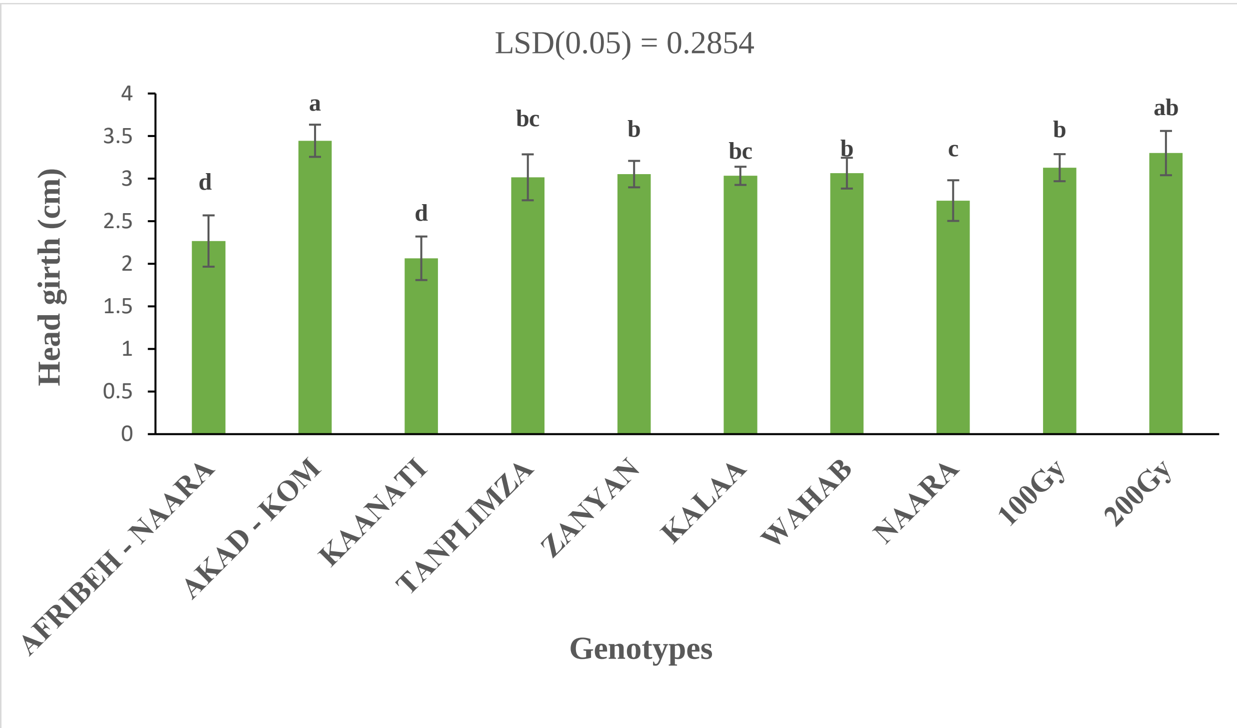


**Figure 8: Effects of genotypes on head girth of millet. Data were obtained from experiment I. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability.**

### 4.1.11 Head Weight

Head weight of the genotypes varied significantly (P < 0.05). For example, Zanyan followed by Tanplimza and Kalaa recorded the highest head weight with mean values of 26.12g 23.97g and 21.85 g respectively (Figure 9). On the other hand, 100Gy and Afribeh–Naara produced the lowest head weight (10.88 g and 11.02) though they were not significantly different from the remaining genotypes.

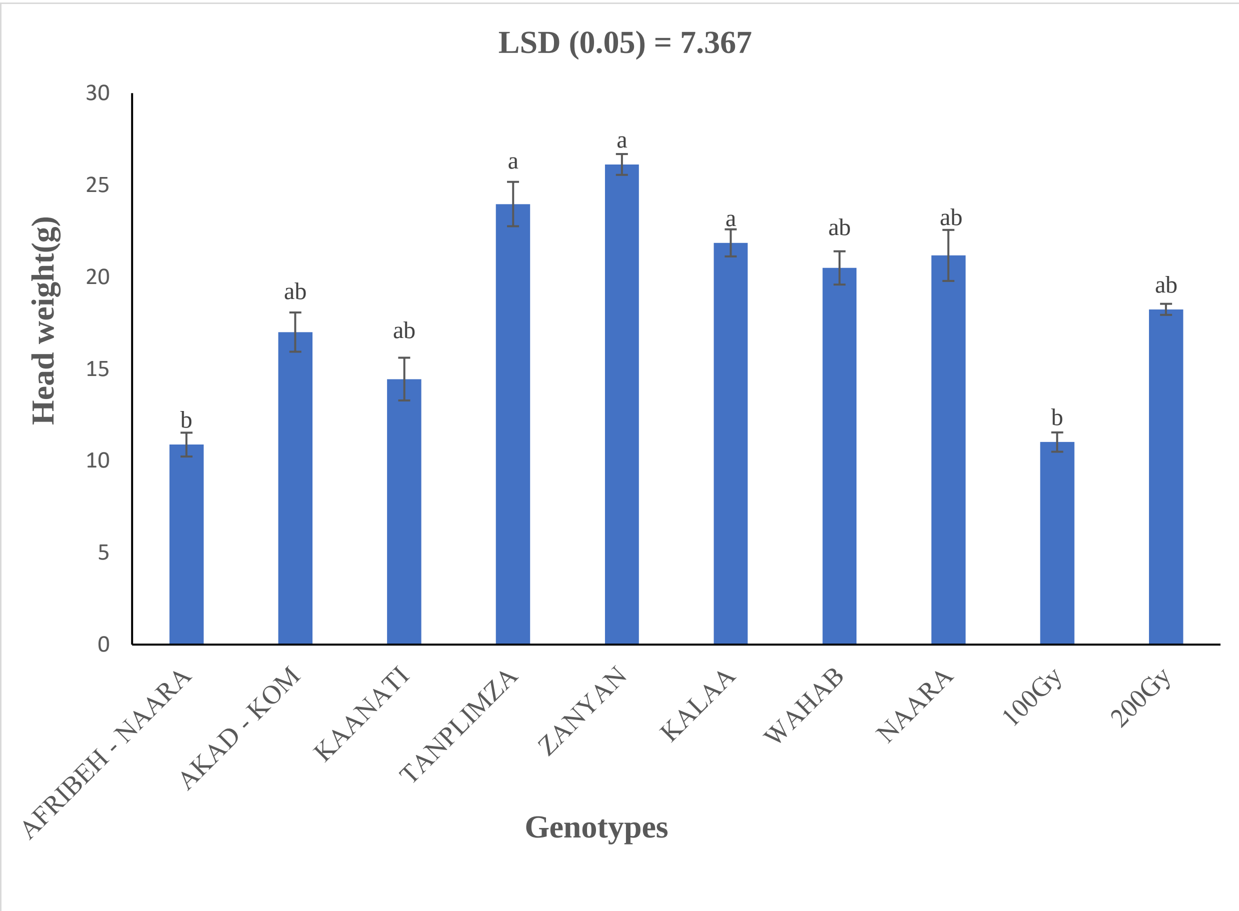


**Figure 9 : Effects of genotypes on head weight of millet. Data were obtained from experiment I. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability.**

### 4.1.8 Total grain yield (kg/ha)

Genotypes varied significantly (P < 0.05) for the total grain yield (Figure 10). The 200 Gy plants recorded the highest grain yield of 1030 kg/ha. This was followed by Akad-kom, Kalaa, and Zanyan (statistically similar at a 5% probability level), with yields of 710, 610 and 500 kg/ha respectively. The genotype Naara recorded the least total grain yield with a mean value of 220 kg/ha.

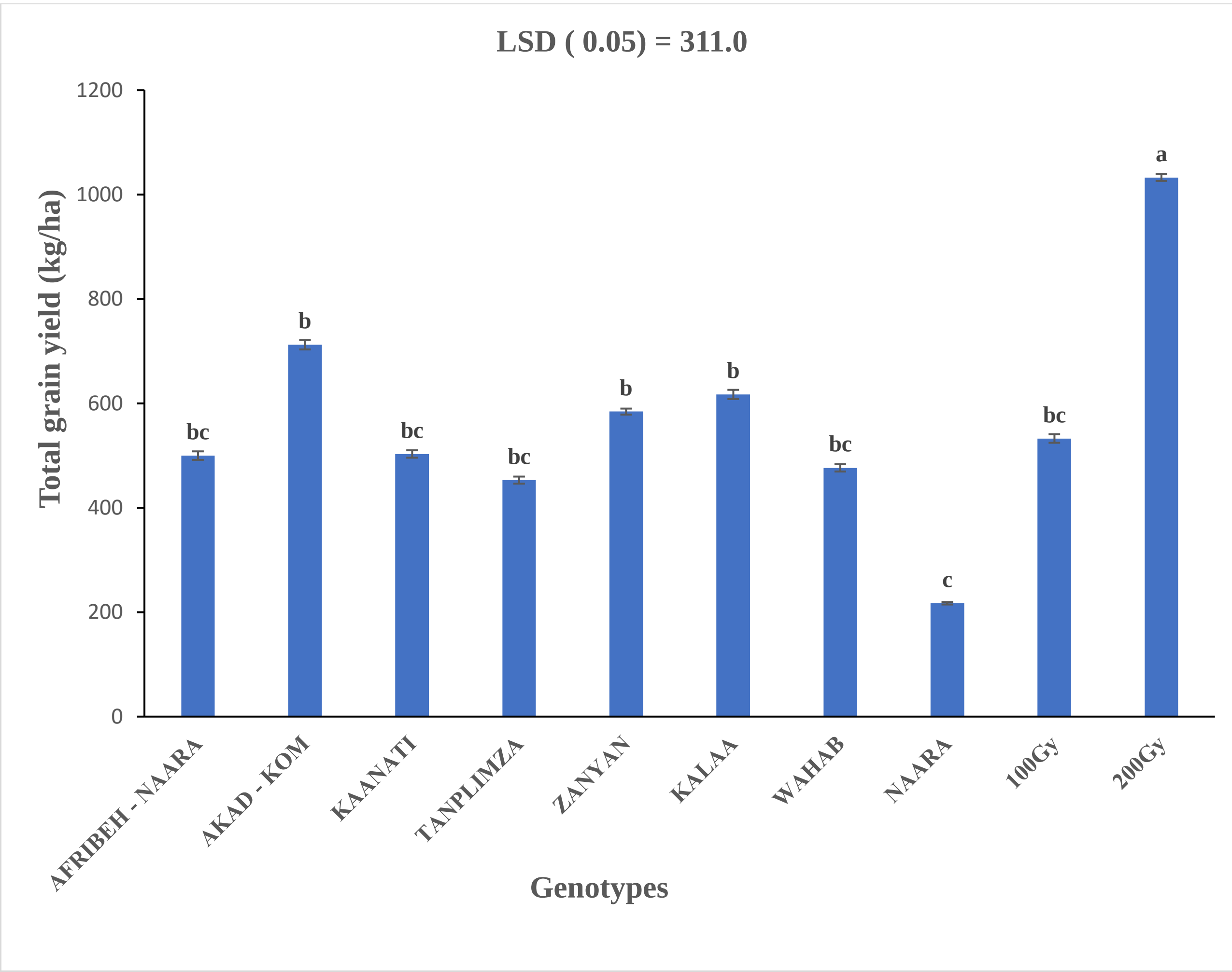


**Figure 10: Effects of genotypes on total grain yield of millet. Data were obtained from experiment I. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability**

## 4.2 Results for Experiment II

### 4.2.1 Establishment

At 4WAP, establishment varied significantly ($P < 0.05$) among the various genotypes with Akad-kom giving the highest establishment of 27 % (Figure 11). The remaining genotypes were not statistically different from each other. However, the genotype 100Gy recorded the least establishment with a percentage mean of 18 %

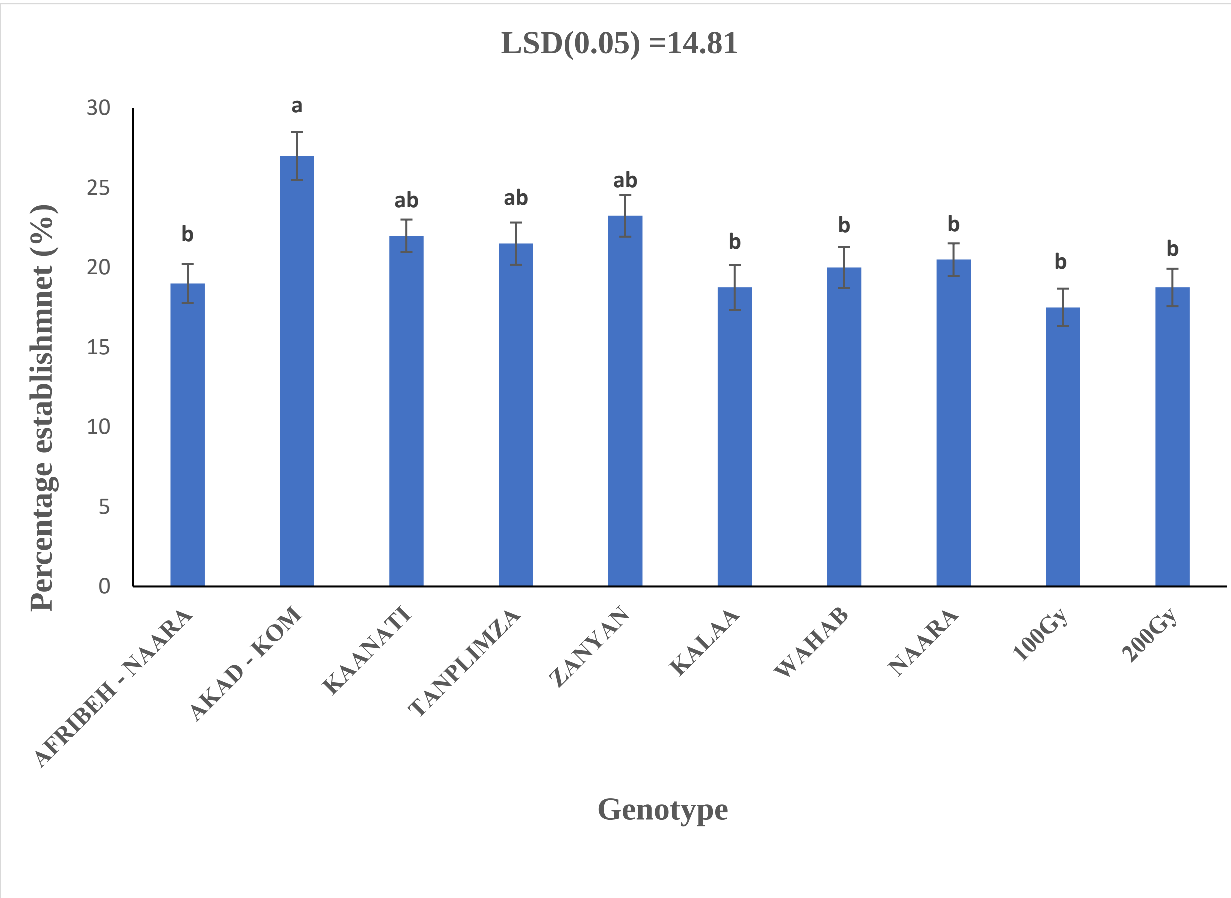


**Figure 11 :Effects of genotypes on percentage establishment of millet. Data were obtained from field experiment II. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability**

### 4.2.2 Days 50 % flowering

The data presented in Figure 12 showed a highly significant difference (P < 0.001) in days to 50 % flowering among genotypes. The least number of days to 50 % flowering was observed among the genotypes Kaanati, Akad-kom, and Afribeh–Naara, with an average value of 44, 44, and 47 days respectively. Tanplimza gave the longest days to 50 % flowering with a mean value of 76 followed by Zanyan, Wahab and 100Gy with a mean value of 71 days.

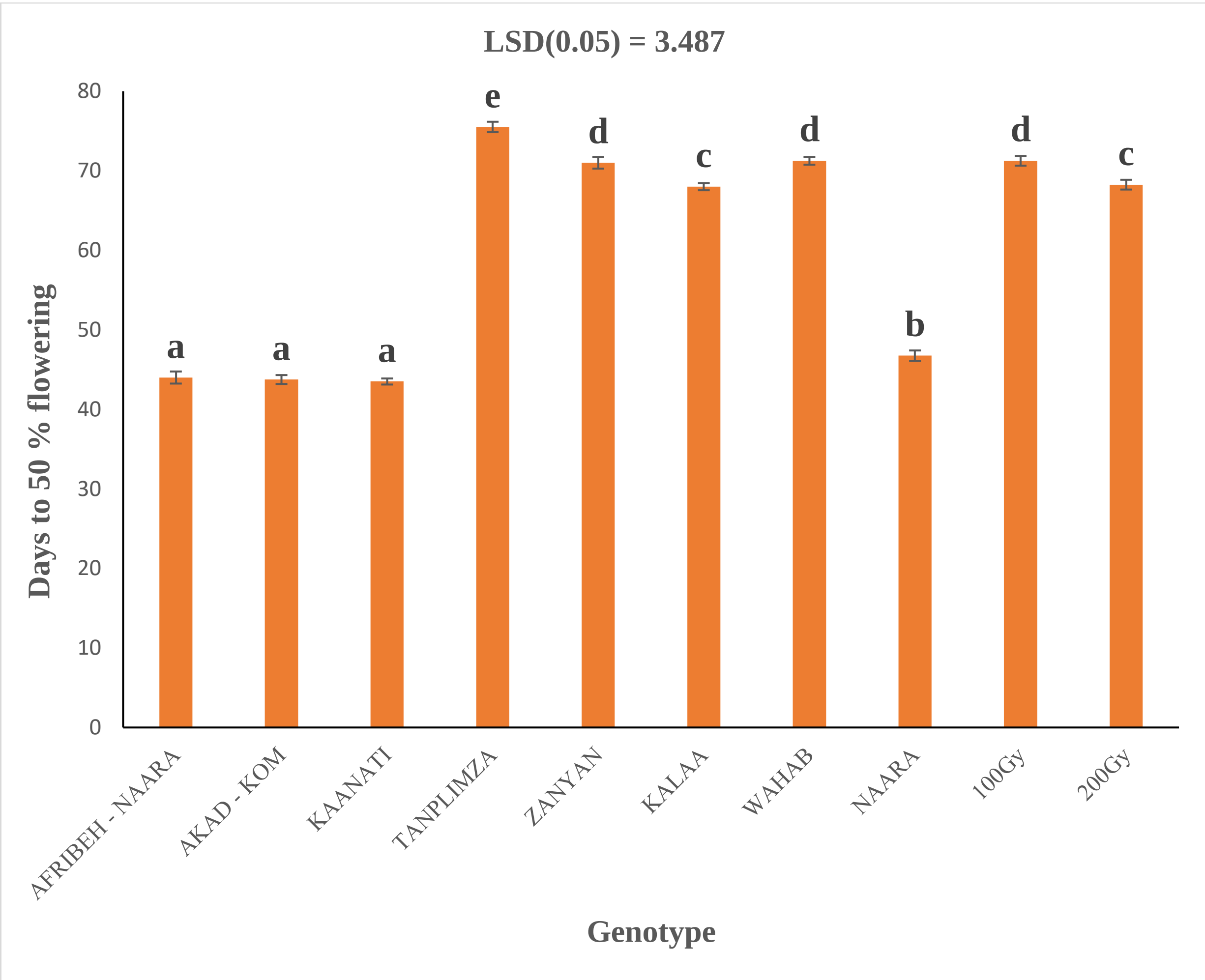


**Figure 12 :Effects of genotypes on days to 50 % flowering of millet. Data were obtained from field experiment II. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability**

### 4.2.3 Plant Height

Also, there were significant variations ($P < 0.05$) among genotypes in terms of plant height at all weeks of data collection. At 4WAP, most of the genotypes were not statistically different except for 100Gy (Figure 13). The various genotypes recorded an average height of 21.22 cm while 100Gy gave a mean height of 15.98 cm. At 6WAP, the genotypes recorded an increase in plant height with Akad-kom and Naara producing the highest height of 99.82 and 98.17 cm respectively followed by Kaanati and Afribeh - Naara while the rest of the genotypes recorded the lowest height with a mean value of 44.77 cm. However, at week 10, Wahab and 200Gy gave the highest height of 180 and 179.6 cm respectively while Afribeh – Naara gave the lowest height with a mean value of 132.7 cm.

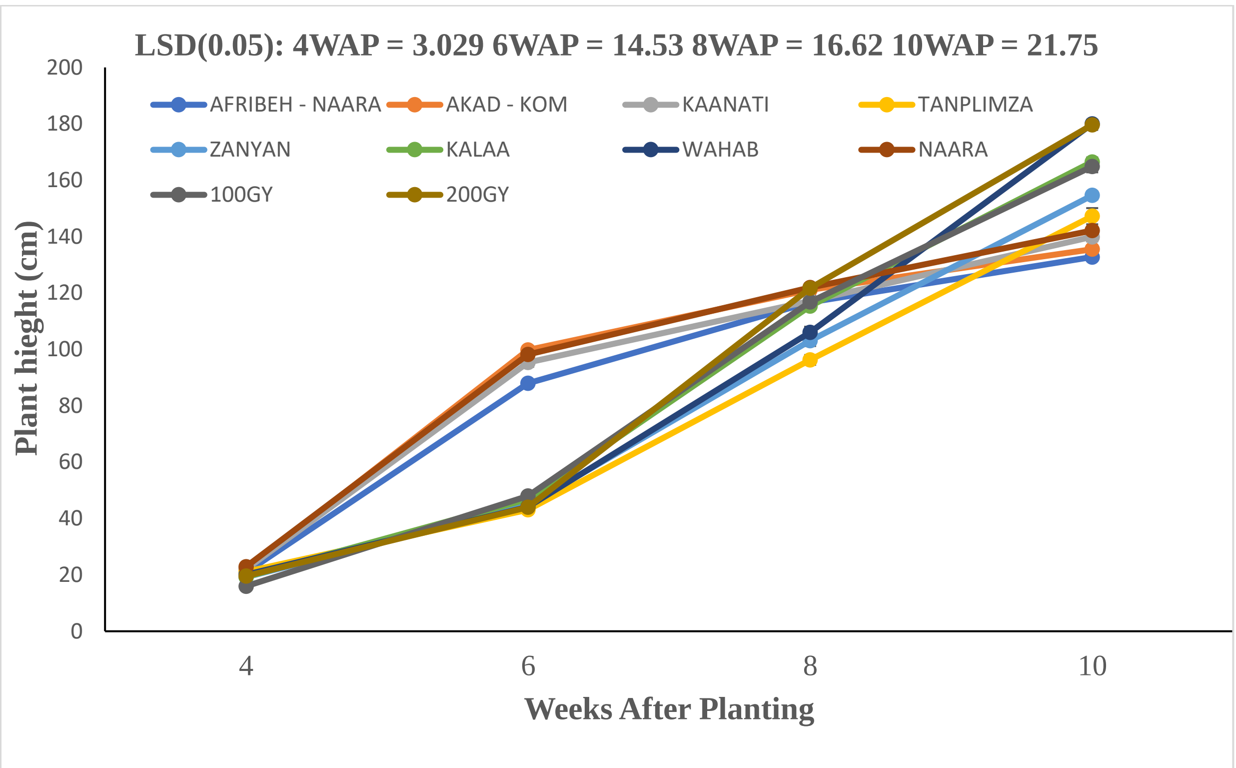


**Figure 13: Effects of genotypes on plant height of millet. Data were obtained from field experiment II. Error bars represent mean ± standard error, Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability.**

### 4.2.4 Number of tillers

The tiller count was highly significantly (P > 0.001) different among the genotypes. Tanplimza recorded the highest number of tillers at 4 weeks after planting with a mean value of 4 followed by 200Gy and Zanyan with a mean value of 3 tillers per plant while the remaining genotypes recorded the least number of tillers with a mean value of 2 (Table 8). At 8 weeks after planting, Kalaa and Zanyan gave the highest number of tiller counts with an average value of 17 while Kaanati and Naara recorded the least number of tillers with a mean value of 6. Kalaa recorded the highest number of tillers at week 10 while Kaanati gave the least number of tillers with a mean value of 7

**Table 8: Effects of genotypes on number of tillers.**

| Genotype | Weeks After Planting (WAP) | | | |
|---|---|---|---|---|
| | 4 | 6 | 8 | 10 |
| Afribeh - Naara | 2 | 4 | 7 | 10 |
| Akad-kom | 2 | 5 | 7 | 9 |
| Kaanati | 2 | 5 | 6 | 7 |
| Tanplimza | 4 | 12 | 16 | 20 |
| Zanyan | 3 | 11 | 17 | 21 |
| Kalaa | 2 | 11 | 17 | 22 |
| Wahab | 2 | 12 | 16 | 20 |
| Naara | 2 | 4 | 6 | 9 |
| 100Gy | 2 | 8 | 13 | 19 |
| 200Gy | 3 | 11 | 16 | 19 |
| LSD (0.05) | 0.8696 | 3.33 | 3.39 | 4.062 |

**Data were obtained from field experiment II in the dry season of the year 2023**

### 4.2.5 Number of Leaves

There was a significant difference (P < 0.05) for genotype for the number of leaves. Akad-kom, Tanplimza, Zanyan, Kalaa, Wahab, and 200 Gy, recorded the highest number of leaves with a mean value of 5 while the remaining genotypes gave the lowest number of leaves at week 4. Again, at 8 and 10 weeks after planting, 200Gy, Tanplimza, Zanyan and Kalaa recorded the highest number of leaves with an average value of 8 and 10 respectively (Table 9). The least number of leaves were observed among Kaanati with mean values of 6 in both weeks. The remaining genotypes showed no significant differences at both weeks.

Table 9 :Effects of genotypes on Number of leaves of millet. .

| Genotype | Weeks After Planting (WAP) | | |
|---|---|---|---|
| | 4 | 8 | 10 |
| Afribeh - Naara | 4 | 6 | 7 |
| Akad-kom | 5 | 6 | 7 |
| Kaanati | 4 | 6 | 6 |
| Tanplimza | 5 | 8 | 10 |
| Zanyan | 5 | 8 | 10 |
| Kalaa | 5 | 8 | 10 |
| Wahab | 5 | 7 | 9 |
| Naara | 4 | 6 | 7 |
| 100Gy | 4 | 7 | 9 |
| 200Gy | 5 | 8 | 10 |
| LSD (0.05) | 0.7689 | 0.9091 | 1.161 |

**Data were obtained from field experiment II in the dry season of the year 2023**

### 4.2.6 Leaf Area Index

Table 10 showed that the various genotypes for leaf area index were highly significantly different ($P < 0.001$). At 4 weeks after planting, the genotype Naara produced the highest leaf area index with a mean value of 0.119 followed by Akad-kom and Afribeh -Naara with mean values of 0.09 while 100Gy recorded the lowest leaf area index of 0.04. The 200Gy genotype at both 6WAP and 8WAP recorded the highest leaf area index with mean values of 0.26 and 0.63 respectively while 100Gy recorded the least Leaf Area Index with a mean value of 0.16 at week 6 and Kaanati gave the lowest area index at week 8 with an average value of 0.33. At week 10, the genotype Tanplimza produced the highest leaf area index of 1.00 followed by 200Gy, Kalaa and Zanyan with mean value of 0.92, 0.97 respectively. In that same week, the genotypes Akad-kom, Afribeh -Naara, Kaanati and Naara recorded the least leaf area index with a mean value of 0.5

**Table 10: Effects of genotypes on leaf area index.**

| Genotype | Weeks After planting(WAP) | | | |
|---|---|---|---|---|
| | 4 | 6 | 8 | 10 |
| Afribeh - Naara | 0.094 | 0.230 | 0.345 | 0.505 |
| Akad-kom | 0.091 | 0.197 | 0.368 | 0.575 |
| Kaanati | 0.073 | 0.180 | 0.333 | 0.513 |
| Tanplimza | 0.074 | 0.200 | 0.569 | 1.003 |
| Zanyan | 0.067 | 0.188 | 0.559 | 0.916 |
| Kalaa | 0.063 | 0.207 | 0.617 | 0.968 |
| Wahab | 0.065 | 0.262 | 0.493 | 0.889 |
| Naara | 0.119 | 0.233 | 0.355 | 0.570 |
| 100Gy | 0.040 | 0.158 | 0.522 | 0.860 |
| 200Gy | 0.087 | 0.261 | 0.627 | 0.918 |
| LSD (0.05) | 0.033 | 0.037 | 0.075 | 0.115 |

**Data were obtained from field experiment II in the dry season of the year 2023**

#### 4.2.7 Chlorophyll Content

The various genotypes for Chlorophyll content differed highly significantly ($P < 0.001$) at all weeks. At 4WAP, the Naara recorded the highest chlorophyll content with a mean value of 35.25 spad unit while Afribeh – Naara produced the least chlorophyll content (28.63 spad units) (Table 11). However, at 6WAP, Afribeh – Naara recorded the highest chlorophyll content followed by Naara with mean values of 54.92 spad units and 51.12 spad units respectively. Wahab, Kalaa and Zanyan recorded the least chlorophyll content in that same week with a mean value of 43 spad units. At 8 WAP, Akad-kom and Afribeh – Naara produced the highest chlorophyll content with mean values of 60.6 and 59.67 spad units respectively while the lowest chlorophyll contents were observed among the remaining genotypes which were statistically not different from each other with a mean value of 55.2 spad unit. At 10WAP, Afribeh – Naara, Akad-kom, Kaanati, and Naara recorded a significant decrease in chlorophyll content with a mean value of 33.12 spad unit, 34.72 spad unit, 34.82 spad unit and 35.82 spad unit respectively whereas 200Gy and Kalaa recorded an increase in chlorophyll content compared to the previous weeks after planting with mean values of 49.67 spad unit and 49.77spad unit respectively.

**Table 11: Effects of genotypes on Chlorophyll content**.

| Genotype | Weeks After Planting (WAP) | | | |
|---|---|---|---|---|
| | 4 | 6 | 8 | 10 |
| Afribeh - Naara | 28.63 | 54.92 | 59.67 | 33.12 |
| Akad-kom | 28.78 | 48.38 | 60.6 | 34.72 |
| Kaanati | 30.25 | 47.48 | 54.85 | 34.82 |
| Tanplimza | 30.85 | 47.2 | 54.92 | 44.62 |
| Zanyan | 29.2 | 43.7 | 52.22 | 47.5 |
| Kalaa | 31.15 | 43.28 | 56.37 | 49.77 |
| Wahab | 31.43 | 43.73 | 55.17 | 48.12 |
| Naara | 35.25 | 51.12 | 55.7 | 35.82 |
| 100Gy | 31.28 | 45.38 | 54.1 | 44.57 |
| 200Gy | 34.33 | 46.85 | 54.32 | 49.67 |
| LSD(0.05) | 2.726 | 6.27 | 4.085 | 8.552 |



**Data were obtained from field experiment II in the dry season of the year 2023**

### 4.2.8 Biomass Accumulation

Again, the genotypes were highly significantly different (P < 0.001) for dry-weight matter accumulation. At harvest, the genotype Kalaa recorded the highest dry matter content with a mean value of 0.24 kg (Figure 14) followed by Wahab with a mean value of 0.22 kg. 100Gy and Zanyan were statistically similar with an average value of 0.2 kg. Akad-kom and Kaanati recorded the least biomass accumulation of 0.09 kg and 0.10 kg respectively.



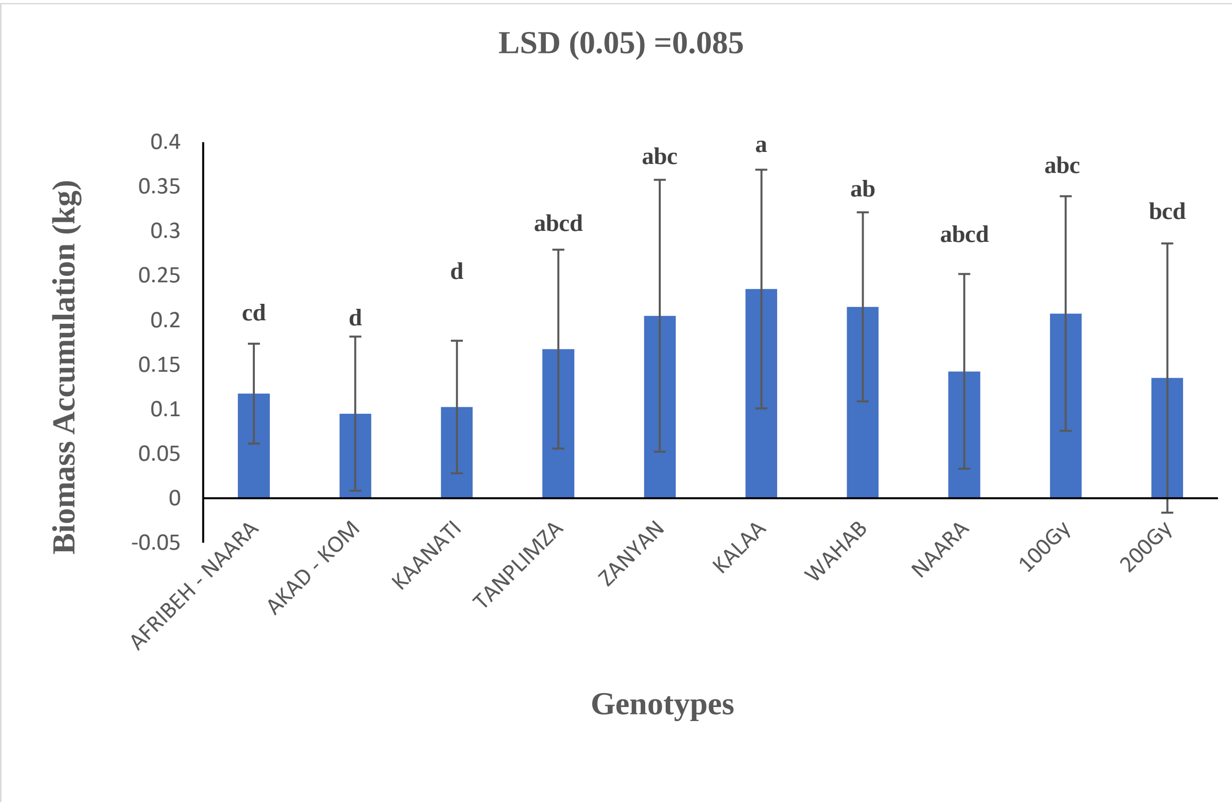


**Figure 14: Effects of genotypes on biomass accumulation. Data were obtained from field experiment II. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability**

### 4.2.9 Head Length

Figure 15 shows the highly significant (P > 0.001) variation for head length which is influenced by the various types of genotypes. The genotype Kaanati recorded the highest length with a mean value of 23 cm followed by Afribeh- Naara with a mean length of 21.9 cm while the genotype Akad-kom gave the lowest length of 11.6 cm. The genotypes Wahab, Naara 100Gy and 200Gy were not statistically different with a mean value of 18 cm.

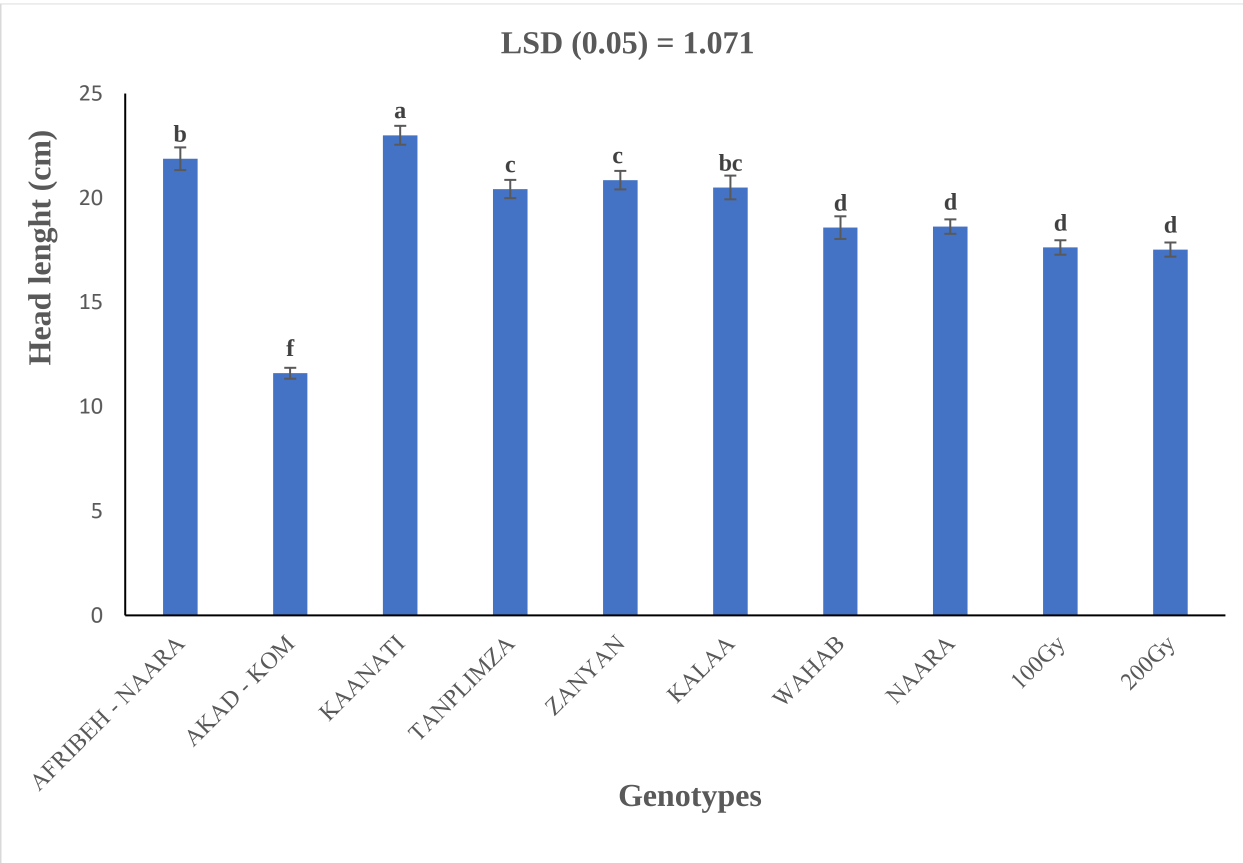


**Figure 15: Effects of genotypes on head length. Data were obtained from field experiment II. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability.**

### 4.2.10 Head Girth

Genotypes showed significant (P < 0.001) differences in the head growth of pearl millet. Kalaa and Akad-kom recorded the greatest head girth at harvest with a mean value of 3.0 cm and 2.9 respectively (Figure 16), while Kaanati and Afribeh – Naara recorded lower girth values of 1.64 cm and 2.2 cm respectively. The rest of the genotypes were statistically the same with a mean value of 2.5 cm

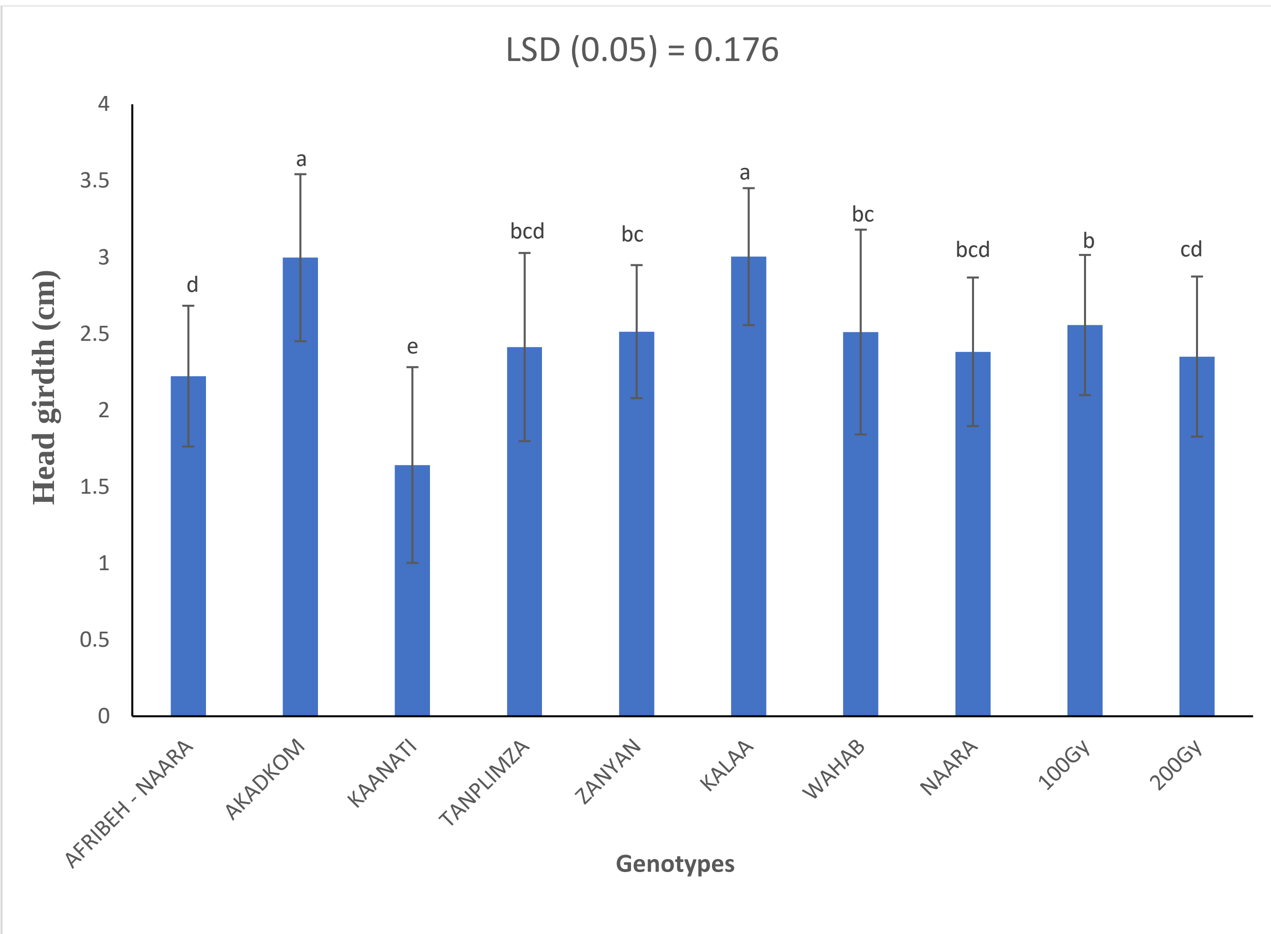


**Figure 16 : Effects of genotypes on head growth. Data were obtained from field experiment II . Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability.**

### 4.2.11 Thousand seed weight

At harvest, thousand seed weights varied highly significantly (P > 0.001) among the various genotypes (Figure 18). Afribeh – Naara recorded the highest seed weight of 12.05 g followed by Kaanati with a mean value of 11.45 g while Tanplimza and Wahab recorded the lowest seed weight with a mean value of 5.15 g cm and 5.63 g respectively. All the other genotypes showed statistical indifference to each other with a mean value of 9 g with the exception of the genotype Zanyan

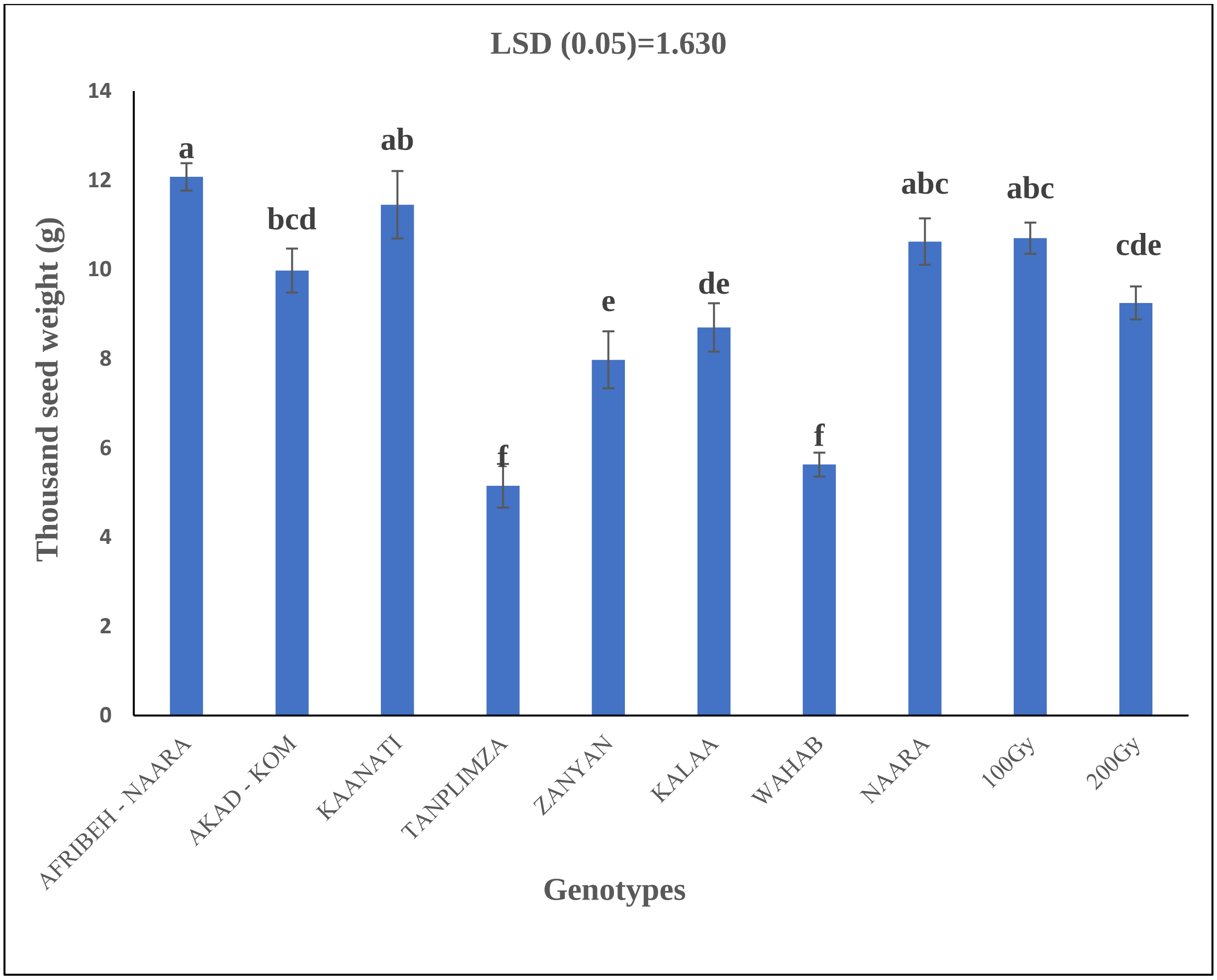


**Figure 17: Effects of genotypes on thousand seed weight. Data were obtained from field experiment II. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability.**

### 4.2.12 Total Grain Yield

Grain yield varied highly significantly (P < 0.001) among the various genotypes at harvest (Figure 18). The genotype Akad-kom gave the highest grain yield with a mean value of 13.48 kg/ha followed by Naara with a mean value of 11.95 kg/ha while the genotypes Tanplimza and Zanyan gave the lowest grain yield with mean values of 1.62 kg/ha and 1.02 kg/ha. The remaining genotypes were not statistically different from each other regarding grain yield.

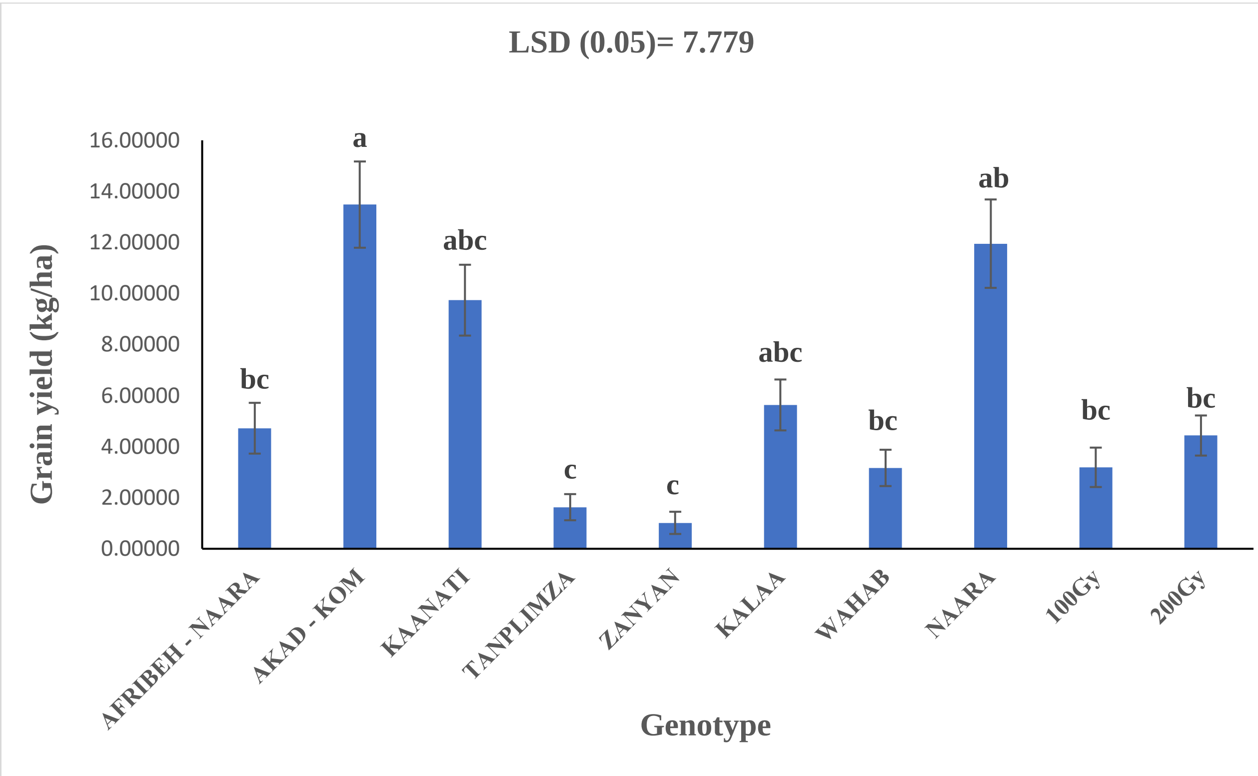


**Figure 18 :Effects of genotypes on grain yield. Data were obtained from field experiment II. Error bars represent mean ± standard error. Genotypes with the same or similar letters are not significantly different at the 0.05 level of probability.**

### 4.2.13 Water Use Efficiency (WUE) and Harvest Index (HI)

Data collected on Water Use Efficiency varied highly significantly among the genotypes (P< 0.05). The genotype Akad-kom recorded the highest water use efficiency with a mean value of 0.036 followed by Naara with a mean value of 0.032 (Table 12). The genotypes Zanyan, Tamplimza and 100Gy recorded the least water use efficiency with an average of 0.005. Again, genotypes varied significantly (P < 0.05) for the harvest Index. The genotype Akad-kom recorded the highest harvest index with a mean value of 175 followed by Naara with a mean value of 144 while the genotype Zanyan and Tanplimza gave the least harvest index with mean values of 5 and 9 respectively.

**Table 12 :Effects of genotypes on water use efficiency and harvest index.**

| Genotypes | Parameters | |
|---|---|---|
| | Water Use Efficiency | Harvest Index |
| Afribeh - Naara | 0.013 | 42 |
| Akad-kom | 0.036 | 175 |
| Kaanati | 0.026 | 98 |
| Tanplimza | 0.004 | 9 |
| Zanyan | 0.003 | 5 |
| Kalaa | 0.015 | 25 |
| Wahab | 0.009 | 14 |
| Naara | 0.032 | 114 |
| 100gy | 0.009 | 17 |
| 200gy | 0.0119 | 59 |
| LSD(0.05) | 0.01987 | 105.8 |

**Data were obtained from field experiment II in the dry season of the year 2023**

### 4.3 Impact of drought stress on the genotypes

The summary tables reveal the significant variability among genotypes due to the impact of water stress in their responses to data collected in both experiments. The marginal differences were calculated using the means of the parameters measured for each genotype. Terminal data were used for all continuous variables (parameters).

**Table 13: Variations as influenced by drought stress on the genotype Afribeh - Naara**

| Parameters | Experiment I | Experiment II | Variation due to water stress |
|---|---|---|---|
| Establishment | 59.4 | 19 | 40.4 |
| Days to 50 % flowering | 47 | 44 | 3 |
| Number of tillers | 7 | 10 | -3** |
| Plant Height | 152 | 133 | 19 |
| Number of Leaves | 8 | 7 | 1 |
| Leaf Area Index | 0.869 | 0.505 | 0.364 |
| Chlorophyll Content | 60.52 | 33.12 | 27.4 |
| Head length | 24.15 | 21.87 | 2.28 |
| Head Girth | 2.7 | 2.2 | 0.5 |
| Head weight | 12.22 | 17.77 | -5.55** |
| Biomass Accumulation | 0.495 | 0.118 | 0.377 |
| Thousand Seed weight | 16.6 | 12.8 | 3.8 |
| Total grain yield | 212.5 | 4.72 | 207.78 |

**The mean values of experiment II were deducted from experiment I. The symbol (**) denotes a negative change in mean values.**

**Table 14: Variations as influenced by drought stress on the genotype Akad-kom**

| Parameters | Experiment I | Experiment II | Variation due to water stress |
|---|---|---|---|
| Establishment | 75.3 | 27 | 48.3 |
| Days to 50 % flowering | 49 | 44 | 5.25 |
| Number of tillers | 5 | 9 | -4** |
| Plant Height | 144 | 136 | 8 |
| Number of Leaves | 8 | 7 | 1 |
| Leaf Area Index | 0.91 | 0.575 | 0.335 |
| Chlorophyll Content | 60.92 | 34.74 | 26.18 |
| Head length | 13.97 | 11.6 | 2.37 |
| Head Girth | 3.4 | 2.9 | 0.5 |
| Head weight | 14.8 | 17.59 | -2.79** |
| Biomass Accumulation | 0.425 | 0.095 | 0.33 |
| Thousand Seed weight | 15.3 | 9.98 | 5.32 |
| Total grain yield | 331.25 | 13.48 | 317.77 |

**The mean values of experiment II were deducted from experiment I. The symbol (**) denotes a negative change in mean values.**

**Table 15: Variations as influenced by drought stress on the genotype Kaanati**

| Parameters | Experiment I | Experiment II | Variation due to water stress |
|---|---|---|---|
| Establishment | 63.8 | 22 | 41.8 |
| Days to 50 % flowering | 48 | 44 | 4 |
| Number of tillers | 5 | 7 | -2** |
| Plant Height | 147 | 139 | 8 |
| Number of Leaves | 8 | 6 | 2 |
| Leaf Area Index | 0.867 | 0.513 | 0.354 |
| Chlorophyll Content | 63.22 | 34.83 | 28.39 |
| Head length | 26.82 | 23 | 3.82 |
| Head Girth | 2.1 | 1.6 | 0.5 |
| Head weight | 14.14 | 16.05 | -1.91** |
| Biomass Accumulation | 0.463 | 0.103 | 0.36 |
| Thousand Seed weight | 14.95 | 11.45 | 3.5 |
| Total grain yield | 293.75 | 9.74 | 284.01 |

The mean values of experiment II were deducted from experiment I. The symbol (**) denotes a negative change in mean values.

**Table 16: Variations as influenced by drought stress on the genotype Tanplimza**

| Parameters | Experiment I | Experiment II | Variation due to water stress |
|---|---|---|---|
| Establishment | 49 | 22 | 27 |
| Days to 50 % flowering | 107 | 86 | 21 |
| Number of tillers | 21 | 20 | 1 |
| Plant Height | 147 | 87 | 60 |
| Number of Leaves | 10 | 10 | 0 |
| Leaf Area Index | 1.107 | 1.003 | 0.104 |
| Chlorophyll Content | 48.77 | 44.62 | 4.15 |
| Head length | 25.72 | 20.42 | 5.3 |
| Head Girth | 3 | 2.4 | 0.6 |
| Head weight | 21.85 | 7.31 | 14.54 |
| Biomass Accumulation | 0.503 | 0.168 | 0.335 |
| Thousand Seed weight | 11.45 | 5.15 | 6.3 |
| Total grain yield | 312.5 | 1.63 | 310.87 |

**The mean values of experiment II were deducted from experiment I**

**Table 17: Variations as influenced by drought stress on the genotype Zanyan**

| Parameters | Experiment I | Experiment II | Variation due to water stress |
|---|---|---|---|
| Establishment | 56 | 23 | 33 |
| Days to 50 % flowering | 98 | 81 | 17 |
| Number of tillers | 21 | 21 | 0 |
| Plant Height | 155 | 108 | 47 |
| Number of Leaves | 11 | 10 | 1 |
| Leaf Area Index | 1.4 | 0.916 | 0.484 |
| Chlorophyll Content | 47.25 | 47.5 | -0.25 ** |
| Head length | 25.1 | 16.52 | 8.58 |
| Head Girth | 3.1 | 2.5 | 0.6 |
| Head weight | 22.41 | 8.32 | 14.09 |
| Biomass Accumulation | 1.087 | 0.205 | 0.882 |
| Thousand Seed weight | 12.53 | 7.98 | 4.55 |
| Total grain yield | 437.5 | 1.02 | 436.48 |

**The mean values of experiment II were deducted from experiment I. The symbol (**) denotes a negative change in mean values.**

**Table 18 : Variations as influenced by drought stress on the genotype Kalaa**

| Parameters | Experiment I | Experiment II | Variation due to water stress |
|---|---|---|---|
| Establishment | 61.5 | 19 | 42.5 |
| Days to 50 % flowering | 91 | 78 | 13 |
| Number of tillers | 21 | 21 | 0 |
| Plant Height | 167 | 123 | 44 |
| Number of Leaves | 10 | 10 | 0 |
| Leaf Area Index | 1.122 | 0.968 | 0.154 |
| Chlorophyll Content | 45.62 | 48.12 | -2.5** |
| Head length | 24.7 | 21.42 | 3.28 |
| Head Girth | 3 | 3 | 0 |
| Head weight | 22.14 | 17.39 | 4.75 |
| Biomass Accumulation | 0.6 | 0.235 | 0.365 |
| Thousand Seed weight | 13.38 | 8.7 | 4.68 |
| Total grain yield | 243.75 | 5.63 | 238.12 |

**The mean values of experiment II were deducted from experiment I. The symbol (**) denotes a negative change in mean values.**

**Table 19: Variations as influenced by drought stress on the genotype Wahab**

| Parameters | Experiment I | Experiment II | Variation due to water stress |
|---|---|---|---|
| Establishment | 53.6 | 20 | 33.6 |
| Days to 50 % flowering | 92 | 81 | 11 |
| Number of tillers | 23 | 20 | 3 |
| Plant Height | 180 | 125 | 55 |
| Number of Leaves | 11 | 9 | 2 |
| Leaf Area Index | 1.205 | 0.889 | 0.316 |
| Chlorophyll Content | 45.62 | 48.12 | -2.5** |
| Head length | 24.75 | 18.75 | 6 |
| Head Girth | 3.1 | 2.5 | 0.6 |
| Head weight | 20.53 | 12.82 | 7.71 |
| Biomass Accumulation | 0.498 | 0.215 | 0.283 |
| Thousand Seed weight | 13.23 | 5.63 | 7.6 |
| Total grain yield | 525 | 3.17 | 521.83 |

**The mean values of experiment II were deducted from experiment I. The symbol (**) denotes a negative change in mean values.**

**Table 20:Variations as influenced by drought stress on the genotype Naara**

| Parameters | Experiment I | Experiment II | Variation due to water stress |
|---|---|---|---|
| Establishment | 31 | 21 | 10 |
| Days to 50 % flowering | 50 | 47 | 3 |
| Number of tillers | 5 | 9 | -4** |
| Plant Height | 145 | 142 | 3 |
| Number of Leaves | 8 | 7 | 1 |
| Leaf Area Index | 1.019 | 0.57 | 0.449 |
| Chlorophyll Content | 63.2 | 35.82 | 27.38 |
| Head length | 20.35 | 18.62 | 1.73 |
| Head Girth | 2.7 | 2.4 | 0.3 |
| Head weight | 18.03 | 18.37 | -0.34** |
| Biomass Accumulation | 0.52 | 0.143 | 0.377 |
| Thousand Seed weight | 19.48 | 10.63 | 8.85 |
| Total grain yield | 193.75 | 11.95 | 181.8 |

**The mean values of experiment II were deducted from experiment I. The symbol (**) denotes a negative change in mean values**.

**Table 21:Variations as influenced by drought stress on the genotype 100Gy**

| Parameters | Experiment I | Experiment II | Variation due to water stress |
|---|---|---|---|
| Establishment | 62.5 | 17.5 | 45 |
| Days to 50 % flowering | 90 | 81 | 9 |
| Number of tillers | 22 | 19 | 3 |
| Plant Height | 165 | 115 | 50 |
| Number of Leaves | 10 | 9 | 1 |
| Leaf Area Index | 1.16 | 0.86 | 0.3 |
| Chlorophyll Content | 48.17 | 44.57 | 3.6 |
| Head length | 23 | 17.87 | 5.13 |
| Head Girth | 3.1 | 2.6 | 0.5 |
| Head weight | 12.87 | 15.45 | -2.58** |
| Biomass Accumulation | 0.51 | 0.208 | 0.302 |
| Thousand Seed weight | 10.55 | 10.17 | 0.38 |
| Total grain yield | 706.25 | 3.19 | 703.06 |

**The mean values of experiment II were deducted from experiment I. The symbol (**) denotes a negative change in mean values.**

**Table 22:Variations as influenced by drought stress on the genotype 200Gy**

| Parameters | Experiment I | Experiment II | Variation due to water stress |
|---|---|---|---|
| Establishment | 66 | 19 | 47.15 |
| Days to 50 % flowering | 90 | 78 | 12 |
| Number of tillers | 19 | 19 | 0 |
| Plant Height | 180 | 173 | 7 |
| Number of Leaves | 11 | 10 | 1 |
| Leaf Area Index | 1.706 | 0.918 | 0.788 |
| Chlorophyll Content | 48.45 | 49.67 | -1.22** |
| Head length | 24.35 | 17.77 | 6.58 |
| Head Girth | 3.3 | 2.4 | 0.9 |
| Head weight | 16.1 | 17.99 | -1.89** |
| Biomass Accumulation | 0.58 | 0.135 | 0.445 |
| Thousand Seed weight | 12.43 | 9.25 | 3.18 |
| Total grain yield | 993.75 | 4.44 | 989.31 |

**The mean values of experiment II were deducted from experiment I. The symbol (**) denotes a negative change in mean values.**

# CHAPTER FIVE

# DISCUSSION

## 5.1 Experiment I

### 5.1.1 Growth parameters

The studies suggest that the genotypes impacted the growth and yield of millet. The phases of development were influenced by the expression of traits by genotypes. Germination is a critical stage in seedling establishment and hence an important component of agricultural productivity (Khajeh-Hosseini *et al*., 2003). Percentage establishment associated with landraces remained low with an average of 54 % among the five genotypes and this may have resulted from the slow growth rate of the landraces which affirms the findings of Maqsood and Azam Ali, (2007) who stated that landraces recorded an average seedling establishment of 53 % at 12 days after planting.

The improved varieties; Akad-kom, Afribeh – Naara, and Kaanati together with Naara were observed to have early flowering periods and this can be ascribed to the short vegetative cycle and rapid growth rate of these genotypes. This finding affirms the suggestion made by Shavrukov *et al*. (2017) who stipulated that a shorter vegetative phase and an early flowering time are critical components for terminal drought escape. In an effort to complete their life cycle and reduce their exposure to abiotic stress, plants undergo rapid growth. Álvaro *et al*. (2008) and Isidro *et al*. (2011) also reported that early flowering and rapid life - cycle of plants were consistently associated with improved varieties relative to traditional varieties in wheat.

The highest plant height was recorded among the improved varieties; Afribeh- Naara, Kaanati, and Akad-kom in the early weeks after planting and was consistent till 8WAP. The observation made here might be due to the effective growth rate and short life cycle among these varieties. This finding is in accordance with the reports of Yadav and Rai, (2013) and Serba *et al*. (2020) who stated that the significant performance of pearl millet in semi-arid regions is due to its remarkable photosynthetic efficiency and rapid growth cycle. However, the improved genotype, 200Gy recorded the highest height after 10WAP which agrees with the finding of Lande *et al*. (2018) that gamma radiations enhance plant height in soybeans. A similar report from Dubey *et al*. (2007) shows a significant increase in the height of okra plants after gamma radiation. The distinction among the improved varieties could be attributed to differential growth patterns, plant structure, and mechanism of millet genotypes which corresponds to the findings of Ausiku *et al*., (2022). Under suitable conditions, pearl millet increases tiller production. However, tillers grew profusely among landraces as compared to the improved varieties, which are unique traits for the production of many panicles to facilitate yield increase. These observations confirm the findings of Krishna, (2013) who stated that profuse tillers as well as an increase in plant height are predominant in pearl millet under favorable conditions.

The mutant genotype 200Gy recorded the highest Leaf Area with increasing weeks after planting which could be attributed to increased photosynthetic and cell division which resulted in active leaf production. Again genotypes with the least number of leaves and leaf area index can be ascribed to genotypes exhibiting a high rate of leaf abscission. These findings correspond to the finding of Doughty and Goulden, (2009) that a rapid increase in leaf area index is a result of high leaf production. Research affirms that a high leaf area index is considered a major promoter of dry matter accumulation in plants (Boraiah & Reddy, 2022). A significant increase in dry matter accumulation was observed in the 200Gy genotype probably due to the high leaf area index.

Kaanati among the genotypes recorded the highest chlorophyll content throughout the growing period which can be ascribed to an increase in active cell division which resulted in the development of stomata pigment due to efficient utilization of nutrients and water. These observations positively correlate with the findings of Sage and Zhu (2011) who reported that the photosynthetic pathway of millet enhances the water and nutrient use efficiency which in turn increases chlorophyll content and lowers hydraulic conductivity per unit leaf area.



### 5.1.2 Yield and yield components

High dry matter accumulation was obtained by the Zanyan at harvest. However, Akad-kom, Afribeh – Naara, and Kaanati recorded the lowest dry matter accumulation which can be attributed to early flowering traits and rapid growth rate. These findings correspond to the study of Shavrukov *et al*. (2017) who stated that a short vegetative stage can result in declined dry matter accumulation due to the decrease in duration for photosynthetic production and seed nutrient accumulation under suitable conditions. However, the results indicate that an average of 0.52 kg dry matter accumulation was obtained among the genotypes and show no significant difference between early flowering and late flowering plants except Zanyan. Interestingly, the reports of Shavrukov *et al*. (2017) also denote that early flowering plant produces dry matter content that may be equivalent to or more than late flowering plants, which is an indicator of more active metabolic reaction, increased photosynthesis, efficient use of nutrient and better growth of the early flowering plant with a short life cycle. The photosynthetic pathway of pearl millet boosts the water and nutrient use efficiency which in turn increases biomass allocation and lowers hydraulic conductivity per unit leaf area (Sage and Zhu, 2011).

The 200 Gy plants recorded the highest grain yield which can be largely attributed to the increased photosynthetic activity which resulted in significant accumulation of dry matter. It was observed that the mutant lines (100 Gy and 200 Gy) were characterized as having a large number of tillers and panicles which may also contribute to its substantial yield. This agrees with the recent account that states that productive tillers are the foremost yield attribute and contribute about 54 % of yield in millet. (Krishna *et al.*, 2021).

It was observed that the genotype with a higher number of tillers did not necessarily obtain a higher yield which confirms the study of Nanja Reddy and Sheshshayee (2020) who concluded that grain yield was not increased significantly although the correlation between productive tillers and grain yield was significantly positive. In a related study, there was no significant correlation between the number of tillers and grain yield due to the significant decline in ear size (Jyothsna *et al*., 2016). In contrast to this report, Boraiah and Reddy (2022) stated that the increased number of productive tillers in finger millet was primarily responsible for enhanced grain production.

Results of the present study indicate that a higher grain yield was in response to the grain number per panicle which is in accordance with the findings of Bidinger and Raju (2000) that, in pearl millet, grain yield has a significant relation with grain number. The increased grain yield from 200Gy genotypes can also be attributed to increased head length, weight, and head girth which was observed at harvest. This discovery conforms to the submission of Turbat *et al*. (2023) who stated that the leading factors of increased yield productivity in millet include 1000 seed weight, length of the panicle, and number of seeds per panicle.



## 5.2 Experiment II

### 5.2.1 Growth parameters

Plant growth, development and subsequent yield in general are affected by the environmental conditions in which plants are grown. These conditions include moisture, solar radiation, temperature, and soil acidity. Drought among other abiotic stresses is responsible for impaired mitosis; cell division, elongation and expansion in reduced growth and yield traits in pearl millet.

Drought stress has a significant effect on both morphological and physiological changes which is evident in the vegetative and reproductive phases of pearl millet. Exploration of crops that can adapt to extreme climatic environments is of paramount significance in safeguarding agricultural production in the tropics to attain maximum yield. Drought-tolerant crops can be identified by screening them based on a number of physiological and morphological features, such as relative water content, chlorophyll content, plant height, root length, shoot length, spike fertility, and grain yield per plant (Tiwari *et al*., 2022).

Early flowering is a physiological trait expressed in pearl millet as a drought escape mechanism. This mechanism is in response to an impending terminal stress condition which occurs after a brief vegetative phase (Shavrukov *et al*., 2017). This was observed among the improved varieties; Akad-kom, Kaanati, and Afribeh–Naara, but also reflected in the landrace Naara and was observed to have this intrinsic capacity to escape drought stress. In addition, Shavrukov *et al*. (2017) stipulated that the delay in flowering among the other genotypes can be ascribed to differential responses to photoperiodic requirements due to large genotypic differences among pearl millet varieties although they are considered short-day plants. It was observed that some of the landraces were photoperiod sensitive, which resulted in late flowering with increasing day length which affirms the findings of Upadhyaya (2007). Interestingly, the findings of Sultan *et al*. (2013) also suggest the difference in the flowering cycle among the landraces was a result of photoperiod sensitivity which is an important adaptation mechanism to the environment. Reduced flowering cycle in pearl millet landraces was indeed associated with drought periods (Vigouroux *et al*., 2011).

Drought stress did not significantly affect plant height among the genotypes throughout the growing season. Field observation indicates that plant height increases with increasing weeks after planting. At 4WAP, the genotypes recorded average heights of 21.22 cm and increased drastically as the growth phase progressed. At 10WAP, an average height of 180 cm was obtained by Akad-kom. This profuse growth in height can be attributed to genetic traits of the genotypes which make them tolerant to drought. However, these findings contradict the submission made by Maqsood and Azam Ali, (2007) who stated that water stress imposes a significant reduction in plant height in finger millet.

The reduction in the number of leaves among the landraces as observed in this study could probably be a mechanical response to reducing leaf area under water stress conditions. A similar concern was expressed by Jones *et al*. (1995) that a drought tolerance mechanism is water retention strategy. With small leaf area transpiration in crops is limited due to the small surface area of leaves. A drought-stress condition can disrupt the crop establishment, and growth development pattern and eventually reduction in grain yield (Sankar *et al*., 2007). Stomatal closure due to water stress results in an overabundance of reactive oxygen species (ROS) and oxidative stress. Chlorophyll content among other physiological activities is greatly affected by the impact of drought stress. Chlorophyll content was reduced drastically among genotypes, for instance, the genotypes Akad-kom and Afribeh–Naara, recorded the highest chlorophyll content with an average of 60 spad units in earlier weeks of planting but declined to an average of 32 spad units at 10WAP which can be attributed to the impact of drought stress. These findings confirm the reports of Tiwari *et al*. (2020) who stated that drought stress triggered a significant reduction in chlorophyll, photosynthesis, and relative water content (RWC) but induced proline content. The chlorophyll content is stipulated to reduce under water stress due to the enhanced activity of chlorophyllase, a metabolic enzyme that breaks down chlorophyll. Peroxidase and chlorophyllase increased under extreme drought stress conditions, which led to a drop in chlorophyll concentration (Ajithkumar and Panneerselvam, 2014).

According to Anjum *et al*. (2011), the reduction in chlorophyll content of crops can again be ascribed to a common sign of pigment photooxidation and chlorophyll degradation which is reliant on the severity and duration of drought stress.



**5.2.2 Yield and yield components**

In comparison with the improved varieties, landraces accumulated a significant quantity of dry matter content under a drought-stress environment. The genotype Kalaa recorded the highest dry matter content of 0.24 kg while Akad-kom recorded the least biomass accumulation of 0.09 kg at harvest. According to Yadav (2008), indigenous landraces are recognized as a good source of drought versatility in drier areas due to their potential to produce significant grains, stover yields and higher biomass, than improved populations.

However, the reduction in dry matter production as a result of moisture stress is consistent with the physiological mechanism of closure of stomata for water conservation (Pirasteh-Anosheh *et al*., 2016). Available literature indicates that stomata closure in response to drought tolerance results in low carbon dioxide fixation in crops as well as the reduction in cell division and enlargements. Aside from this phenomenon drought stress is reported to be obstructive to most cellular metabolic activities and growth rate (Nemeskéri *et al*., 2015; Rauf *et al*., 2016). This finding is a reflection of this study with a significant decrease in biomass accumulation as well as grain yield with a minimum of 0.01 kg/ha and 1.01 kg/ha biomass and seed yield, respectively.

The close relationship between the number of tillers and grain yield was not significant among the landraces under drought conditions. Field observation indicates that although Naara recorded the least number of tillers, however, gave the highest grain yield among the landraces which contradicts the findings of Van Oosterom *et al*. (2006) who stated that, genotypes with small – panicled and high number of tillers produce higher grain yield than large – panicled and low tillering landraces.

Yield reduction was highly influenced by drought treatment in many millet genotypes. According to Vadez *et al*. (2012), the most sensitive phase of pearl millet to drought stress is the grain filling stage, which results in a decrease in grain number and size. The study shows a minimum grain yield of 1.02 kg/ha was obtained by Zanyan which affirms a comparable study by Maqsood and Azam Ali (2007) who stated that millet landraces experienced complete yield loss when exposed to drought stress. Nevertheless, substantial yields of 13.5kg/ ha and 11 kg/ha were obtained from early flowering genotypes; Akad-kom and Naara respectively which can be attributed to an increase in photosynthetic activity that impacts the development and cell metabolism of carbon in early flowering plants. Interestingly, reports from these authors suggest that crops with early flowering time and early maturity qualities have the ability to produce more stable and high yields under drought stress (Turner *et al*., 2001; Serraj *et al*., 2003; Khanna-Chopra and Singh, 2015) which can also result in numerous seed produced under water stress in early flowering and early maturing pearl millet and sorghum (Serraj *et al*., 2003). According to Li and Brutnell (2011), several characteristics of millet which include large leaf areas, and dense root systems among others can reduce the impact of drought stress which is evident in the 200 Gy resulting in higher yield. It was observed that the various genotypes might have employed osmotic adjustment mechanisms that keep their cells expanding, active photosynthesis, relative water content, and stomatal conductance for drought adaptation which has been reported by lyas *et al.* (2021)

### 5.2.3 Water Use Efficiency and Harvest Index

Generally, drought stress varied significantly for water use efficiency among the genotypes. Results indicate that the Akad-kom genotype uses water more efficiently followed by Naara and Kaanati which can be ascribed to high accumulation of dry matter content and effective root absorption of available water. This finding is in tune with Zegada-Lizarazu and Iijima (2005) who stated that an increase in water uptake from deep soil horizon sustains transpiration rates and dry matter production as well as enhances their leaf water status. Vadez *et al*. (2013) reported that genotypic variation influences water use efficiency, with different cultivars having different biomass accumulation rates under the same precipitation. Pearl millets are characterized by having subpopulations of early, intermediate, and late-flowering plants that have diversified growth patterns under field conditions and exits with water use efficiency (De Rouw and Winkel, 1998)

WUE is a prime indicator of drought adaptation in millet species under water stress conditions and has become a useful technique for plant screening under drought environments (Ibrahim *et al*., 1986). Another criterion for measuring drought adaptation of plants to drought regions is the harvest index.

Harvest Index (HI) is the ratio of economic yield to dry matter accumulation per plant. The genotype Akad-kom again recorded the highest harvest index followed by Naara which also attributed to high grain yield and dry matter production due to increased photosynthetic and metabolic processes. The increase in harvest index among these genotypes indicates a greater physiological capacity to assemble photosynthates and transform them effectively to economic yield as opined by Wallace *et al*. (1972).

# CHAPTER SIX

# CONCLUSION AND RECOMMENDATION

## 6.1 Conclusion

The results of this study show that the genotypes under the two growing conditions significantly influenced the evaluation of desirable traits. Generally, results on vegetative growth and yield indicate that different plant types are related to adaptability to drought and high productivity. Under a suitable condition the genotypes Akad-kom, Afribeh–Naara, Kaanati and Naara exhibited the best performance with respect to data collected on percentage establishment, days to 50 % flowering, biomass accumulation and grain yield, these attributes highly characterize the genotypes as having early maturing traits.

However, the genotype Akad-kom demonstrated a superior quality among these genotypes and can also be considered a good source of early maturing crops with high-yielding ability. It can be established from all indications that the genotype 200 Gy can also be considered a high-yielding variety of released due to its positive response to data collected on the number of tillers, panicles, biomass accumulation and grain yield. The genotype Zanyan under suitable conditions can also be characterized as having high-yielding ability owing to the large accumulation of dry matter content.

Under drought stress conditions, the response of the genotype varied significantly with respect to the data collected. However, the reproductive phase was much more sensitive to drought stress than vegetative growth. From the results, it can be concluded that the genotypes Akad-kom, Kaanati Naara, Wahab and Kalaa can be considered drought-tolerant varieties due to their positive response to data collected on grain yield, water use efficiency, biomass accumulation and harvest Index. Early flowering time and early maturity were exhibited by the genotypes

Afribeh – Naara, Kaanati, Akad-kom and Naara as drought escape mechanisms. The landraces were photoperiod sensitive which resulted in delayed flowering and late maturity. It can also be concluded that low-tillering genotypes with more large-sized seeds are preferred under ideal growing conditions, but for genotypes with smaller seed sizes, more tillers and panicles are needed to adapt to drought stress.



## 6.2 Recommendation

The research provides a highly informative and significant use of genotypic traits of the 10 germplasm which can be employed for a breeding program.

The results identified four groups of genotypes (Akad-kom, Afribeh–Naara, Kaanati and Naara ) that exhibited earliness in maturity, two sets of genotypes (200 Gy and Akad-kom) as high-yielding genotypes and five genotypes (Akad-kom, Kaanati, Naara, Wahab and Kalaa) with enhanced performance under drought stress. These genotypes could be employed in pearl millet breeding as the parental lines in developing desirable traits.

Further studies should be conducted to explore and develop varieties for their improved desirable traits;

1. A genotype with high-yielding and early maturing ability
2. A genotype with high-yielding and drought-tolerant ability
3. A genotype with the combined traits of high yielding, earliness in maturing and drought tolerant pearl millet.

Development of these improved traits from these parent lines will improve the resilience of pearl millet to climate change and increase food security in developing countries

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# APPENDICES

Field experiment I

Appendix 1 :Analysis of variance for percentage establishment of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 1354.8 | 451.6 | 4.33 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 5028.8 | 558.8 | 5.36 | <.001 |
| Residual | 27 | 2813.5 | 104.2 | | |
| Total | 39 | 9197.0 | | | |

Appendix 2 : Analysis of variance for days to 50 % flowering of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 5.000 | 1.667 | 0.29 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 21378.600 | 2375.400 | 411.13 | <.001 |
| Residual | 27 | 156.000 | 5.778 | | |
| Total | 39 | 21539.600 | | | |

Appendix 3 : Analysis of variance for the number of tillers of pearl millet (Pennisetum glaucum [L.]) at 4WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 16.2750 | 5.4250 | 5.75 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 157.0250 | 17.4472 | 18.49 | <.001 |
| Residual | 27 | 25.4750 | 0.9435 | | |

| | | |
|---|---|---|
| Total | 39 | 198.7750 |

Appendix 4 Analysis of variance for the number of tillers of pearl millet (Pennisetum glaucum [L.]) at 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 39.800 | 13.267 | 2.76 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 578.100 | 64.233 | 13.37 | <.001 |
| Residual | 27 | 129.700 | 4.804 | | |
| Total | 39 | 747.600 | | | |

Appendix 5 :Analysis of variance for the number of tillers of pearl millet (Pennisetum glaucum [L.]) at 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 155.000 | 51.667 | 6.17 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 1328.600 | 147.622 | 17.64 | <.001 |
| Residual | 27 | 226.000 | 8.370 | | |
| Total | 39 | 1709.600 | | | |

Appendix 6 : Analysis of variance for the number of tillers of pearl millet (Pennisetum glaucum [L.]) at 10WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 379.48 | 126.49 | 9.61 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 2141.03 | 237.89 | 18.08 | <.001 |
| Residual | 27 | 355.27 | 13.16 | | |
| Total | 39 | 2875.77 | | | |

Appendix 7 :Analysis of variance for plant height of pearl millet (Pennisetum glaucum [L.]) at 4WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 322.075 | 107.358 | 24.63 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 208.225 | 23.136 | 5.31 | <.001 |
| Residual | 27 | 117.675 | 4.358 | | |
| Total | 39 | 647.975 | | | |

Appendix 8: Analysis of variance for plant height of pearl millet (Pennisetum glaucum [L.]) at 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 586.1 | 195.4 | 1.95 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 28073.7 | 3119.3 | 31.10 | <.001 |
| Residual | 27 | 2708.2 | 100.3 | | |
| Total | 39 | 31368.0 | | | |

Appendix 9 : Analysis of variance for plant height of pearl millet (Pennisetum glaucum [L.]) at 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 2367.5 | 789.2 | 6.02 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 56854.1 | 6317.1 | 48.16 | <.001 |
| Residual | 27 | 3541.8 | 131.2 | | |
| Total | 39 | 62763.4 | | | |

Appendix 10 : Analysis of variance for plant height of pearl millet (Pennisetum glaucum [L.]) at 10WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 4857.3 | 1619.1 | 7.20 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 22976.5 | 2552.9 | 11.36 | <.001 |
| Residual | 27 | 6070.0 | 224.8 | | |
| | | | | | |
| Total | 39 | 33903.8 | | | |

Appendix 11 :Analysis of variance for the number of leaves of pearl millet (Pennisetum glaucum [L.]) at 4WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 2.8750 | 0.9583 | 7.67 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 5.7250 | 0.6361 | 5.09 | <.001 |
| Residual | 27 | 3.3750 | 0.1250 | | |
| | | | | | |
| Total | | 39 | 11.9750 | | |

Appendix 12 : Analysis of variance for the number of leaves of pearl millet (Pennisetum glaucum [L.]) at 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 2.6000 | 0.8667 | 3.39 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 18.5000 | 2.0556 | 8.04 | <.001 |
| Residual | 27 | 6.9000 | 0.2556 | | |
| | | | | | |
| Total | 39 | 28.0000 | | | |

Appendix 13 : Analysis of variance for the number of leaves of pearl millet (Pennisetum glaucum [L.]) at 10WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 4.0000 | 1.3333 | 2.57 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 56.0000 | 6.2222 | 12.00 | <.001 |
| Residual | 27 | 14.0000 | 0.5185 | | |
| Total | 39 | 74.0000 | | | |

Appendix 14: Analysis of variance for chlorophyll content of pearl millet (Pennisetum glaucum [L.]) at 4 WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 29.550 | 9.850 | 2.10 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 303.265 | 33.696 | 7.19 | <.001 |
| Residual | 27 | 126.585 | 4.688 | | |
| Total | 39 | 459.400 | | | |

Appendix 15: Analysis of variance for chlorophyll content of pearl millet (Pennisetum glaucum [L.]) at 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 90.057 | 30.019 | 8.38 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 848.370 | 94.263 | 26.32 | <.001 |
| Residual | 27 | 96.691 | 3.581 | | |
| Total | 39 | 1035.118 | | | |

Appendix 16 : Analysis of variance for chlorophyll content of pearl millet (Pennisetum glaucum [L.]) at 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 66.71 | 22.24 | 1.97 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 1464.32 | 162.70 | 14.41 | <.001 |
| Residual | 27 | 304.94 | 11.29 | | |
| Total | 39 | 1835.97 | | | |

Appendix 17 : Analysis of variance for chlorophyll content of pearl millet (Pennisetum glaucum [L.]) at 10WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 173.439 | 57.813 | 5.97 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 1970.935 | 218.993 | 22.60 | <.001 |
| Residual | 27 | 261.674 | 9.692 | | |
| Total | 39 | 2406.048 | | | |



Appendix 18 : Analysis of variance for leaf area index of pearl millet (Pennisetum glaucum [L.]) at 4WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.028705 | 0.009568 | 6.88 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 0.088945 | 0.009883 | 7.11 | <.001 |
| Residual | 27 | 0.037549 | 0.001391 | | |
| Total | 39 | 0.155198 | | | |

Appendix 19 : Analysis of variance for leaf area index of pearl millet (Pennisetum glaucum [L.]) at 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.241193 | 0.080398 | 8.08 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 0.165552 | 0.018395 | 1.85 | 0.105 |
| Residual | 27 | 0.268499 | 0.009944 | | |
| | | | | | |
| Total | 39 | 0.675244 | | | |

Appendix 20 : Analysis of variance for leaf area index of pearl millet (Pennisetum glaucum [L.]) at 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.26302 | 0.08767 | 4.85 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 0.63538 | 0.07060 | 3.91 | 0.003 |
| Residual | 27 | 0.48792 | 0.01807 | | |
| | | | | | |
| Total | 39 | 1.38632 | | | |

Appendix 21: Analysis of variance for leaf area index of pearl millet (Pennisetum glaucum [L.]) at 10WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.50376 | 0.16792 | 4.60 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 2.43596 | 0.27066 | 7.41 | <.001 |
| Residual | 27 | 0.98618 | 0.03653 | | |
| | | | | | |
| Total | 39 | 3.92590 | | | |

Appendix 22: Analysis of variance for biomass accumulation of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.08058 | 0.02686 | 1.91 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 1.29154 | 0.14350 | 10.21 | <.001 |
| Residual | 27 | 0.37932 | 0.01405 | | |
| Total | 39 | 1.75144 | | | |

Appendix 23 : Analysis of variance for total grain yield of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 294128. | 98043. | 2.13 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 1576251. | 175139. | 3.81 | 0.003 |
| Residual | 27 | 1240901. | 45959. | | |
| Total | 39 | 3111280. | | | |

Appendix 24 : Analysis of variance for thousand seed weight of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 31.204 | 10.401 | 1.81 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 250.901 | 27.878 | 4.85 | <.001 |
| Residual | 27 | 155.311 | 5.752 | | |
| Total | 39 | 437.416 | | | |

Appendix 25: Analysis of variance for head length of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 10.285 | 3.428 | 1.11 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 493.214 | 54.802 | 17.80 | <.001 |
| Residual | 27 | 83.140 | 3.079 | | |
| Total | 39 | 586.639 | | | |

Appendix 26: Analysis of variance for head girth of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.36345 | 0.12115 | 3.13 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 6.84858 | 0.76095 | 19.67 | <.001 |
| Residual | 27 | 1.04454 | 0.03869 | | |
| Total | 39 | 8.25657 | | | |

Appendix 27: Analysis of variance for head weight of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 148.83 | 49.61 | 1.92 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 575.02 | 63.89 | 2.48 | 0.033 |
| Residual | 27 | 696.17 | 25.78 | | |
| Total | 39 | 1420.02 | | | |

Field experiment II

Appendix 28: Analysis of variance for percentage establishment of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 898.07 | 299.36 | 23.28 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 278.52 | 30.95 | 2.41 | 0.038 |
| Residual | 27 | 347.17 | 12.86 | | |
| Total | 39 | 1523.77 | | | |

Appendix 29: Analysis of variance for days to 50 % flowering of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 3.875 | 1.292 | 0.51 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 12877.025 | 1430.781 | 569.15 | <.001 |
| Residual | 27 | 67.875 | 2.514 | | |
| Total | 39 | 12948.775 | | | |

Appendix 30 : Analysis of variance for days to 50 % flowering of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 3.875 | 1.292 | 0.51 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 12877.025 | 1430.781 | 569.15 | <.001 |
| Residual | 27 | 67.875 | 2.514 | | |
| Total | 39 | 12948.775 | | | |

Appendix 31 : Analysis of variance for the number of tillers of pearl millet (Pennisetum glaucum [L.]) at 4WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| REP stratum | 3 | 3.8000 | 1.2667 | 3.53 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 14.9000 | 1.6556 | 4.61 | <.001 |
| Residual | 27 | 9.7000 | 0.3593 | | |
| Total | 39 | 28.4000 | | | |



Appendix 32: Analysis of variance for the number of tillers of pearl millet (Pennisetum glaucum [L.]) at 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 11.475 | 3.825 | 0.73 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 473.225 | 52.581 | 9.98 | <.001 |
| Residual | 27 | 142.275 | 5.269 | | |
| Total | 39 | 626.975 | | | |

Appendix 33: Analysis of variance for the number of tillers of pearl millet (Pennisetum glaucum [L.]) at 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 26.200 | 8.733 | 1.19 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 872.600 | 96.956 | 13.17 | <.001 |
| Residual | 27 | 198.800 | 7.363 | | |
| Total | 39 | 1097.600 | | | |

Appendix 34: Analysis of variance for the number of tillers of pearl millet (Pennisetum glaucum [L.]) at 10WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| REP stratum | 3 | 55.075 | 18.358 | 2.34 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 1247.225 | 138.581 | 17.68 | <.001 |
| Residual | 27 | 211.675 | 7.840 | | |
| Total | 39 | 1513.975 | | | |



Appendix 35 : Analysis of variance for plant height of pearl millet (Pennisetum glaucum [L.]) at 4WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 240.250 | 80.083 | 15.06 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 140.625 | 15.625 | 2.94 | 0.014 |
| Residual | 27 | 143.605 | 5.319 | | |
| Total | 39 | 524.480 | | | |

Appendix 36 : Analysis of variance for plant height of pearl millet (Pennisetum glaucum [L.]) at 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 342.85 | 114.28 | 4.31 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 24609.61 | 2734.40 | 103.19 | <.001 |
| Residual | 27 | 715.45 | 26.50 | | |
| Total | 39 | 25667.90 | | | |

Appendix 37: Analysis of variance for plant height of pearl millet (Pennisetum glaucum [L.]) at 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 952.33 | 317.44 | 3.26 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 2787.94 | 309.77 | 3.18 | 0.009 |
| Residual | 27 | 2628.87 | 97.37 | | |
| Total | 39 | 6369.14 | | | |



Appendix 38 : Analysis of variance for plant height of pearl millet (Pennisetum glaucum [L.]) at 10WAP

| of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 1823.4 | 607.8 | 4.02 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 11144.1 | 1238.2 | 8.19 | <.001 |
| Residual | 27 | 4080.3 | 151.1 | | |
| Total | 39 | 17047.8 | | | |

Appendix 39: Analysis of variance for the number of leaves of pearl millet (Pennisetum glaucum [L.]) at 4WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 3.6750 | 1.2250 | 4.37 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 6.1250 | 0.6806 | 2.43 | 0.036 |
| Residual | 27 | 7.5750 | 0.2806 | | |
| Total | 39 | 17.3750 | | | |

Appendix 40 : Analysis of variance for the number of leaves of pearl millet (Pennisetum glaucum [L.]) at 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 11.475 | 3.825 | 0.73 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 473.225 | 52.581 | 9.98 | <.001 |
| Residual | 27 | 142.275 | 5.269 | | |
| Total | 39 | 626.975 | | | |



Appendix 41: Analysis of variance for the number of leaves of pearl millet (Pennisetum glaucum [L.]) at 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 26.200 | 8.733 | 1.19 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 872.600 | 96.956 | 13.17 | <.001 |
| Residual | 27 | 198.800 | 7.363 | | |
| Total | 39 | 1097.600 | | | |

Appendix 42: Analysis of variance for the number of leaves of pearl millet (Pennisetum glaucum [L.]) at 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 55.075 | 18.358 | 2.34 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 1247.225 | 138.581 | 17.68 | <.001 |
| Residual | 27 | 211.675 | 7.840 | | |
| Total | 39 | 1513.975 | | | |

Appendix 43 : Analysis of variance for chlorophyll content of pearl millet (Pennisetum glaucum [L.]) at 4WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 237.807 | 79.269 | 22.46 | |

| | | | | | |
|---|---|---|---|---|---|
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 174.746 | 19.416 | 5.50 | <.001 |
| Residual | 27 | 95.311 | 3.530 | | |
| Total | 39 | 507.864 | | | |



Appendix 44: Analysis of variance for chlorophyll content of pearl millet (Pennisetum glaucum [L.]) at 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 61.76 | 20.59 | 1.10 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 478.89 | 53.21 | 2.85 | 0.017 |
| Residual | 27 | 504.22 | 18.67 | | |
| Total | 39 | 1044.87 | | | |

Appendix 45: Analysis of variance for chlorophyll content of pearl millet (Pennisetum glaucum [L.]) at 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 29.475 | 9.825 | 1.24 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 233.204 | 25.912 | 3.27 | 0.008 |
| Residual | 27 | 214.040 | 7.927 | | |
| Total | 39 | 476.719 | | | |

Appendix 46: Analysis of variance for chlorophyll content of pearl millet (Pennisetum glaucum [L.]) at 10WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| REP stratum | 3 | 473.26 | 157.75 | 4.54 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 1684.85 | 187.21 | 5.39 | <.001 |
| Residual | 27 | 938.02 | 34.74 | | |
| | | | | | |
| Total | 39 | 3096.13 | | | |



Appendix 47: Analysis of variance for leaf area index of pearl millet (Pennisetum glaucum [L.]) at 4WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.0097403 | 0.0032468 | 6.24 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 0.0167575 | 0.0018619 | 3.58 | 0.005 |
| Residual | 27 | 0.0140583 | 0.0005207 | | |
| | | | | | |
| Total | 39 | 0.0405562 | | | |

Appendix 48 : Analysis of variance for leaf area index of pearl millet (Pennisetum glaucum [L.]) at 6WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.0060152 | 0.0020051 | 3.16 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 0.0421098 | 0.0046789 | 7.38 | <.001 |
| Residual | 27 | 0.0171223 | 0.0006342 | | |
| | | | | | |
| Total | 39 | 0.0652473 | | | |

Appendix 49: Analysis of variance for leaf area index of pearl millet (Pennisetum glaucum [L.]) at 8WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|

| | | | | | |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.003006 | 0.001002 | 0.37 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 0.499712 | 0.055524 | 20.71 | <.001 |
| Residual | 27 | 0.072381 | 0.002681 | | |
| | | | | | |
| Total | 39 | 0.575099 | | | |



Appendix 50: Analysis of variance for leaf area index of pearl millet (Pennisetum glaucum [L.]) at 10WAP

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.038381 | 0.012794 | 2.05 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 1.490338 | 0.165593 | 26.59 | <.001 |
| Residual | 27 | 0.168115 | 0.006226 | | |
| | | | | | |
| Total | 39 | 1.696833 | | | |

Appendix 51: Analysis of variance for biomass accumulation of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.014347 | 0.004782 | 1.40 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 0.092822 | 0.010314 | 3.03 | 0.012 |
| Residual | 27 | 0.091928 | 0.003405 | | |
| | | | | | |
| Total | 39 | 0.199097 | | | |

Appendix 52: Analysis of variance for total grain yield of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 371.49 | 123.83 | 4.31 | |
| | | | | | |
| REP.*Units* stratum | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| TREATMENT | 9 | 677.28 | 75.25 | 2.62 | 0.026 |
| Residual | 27 | 776.14 | 28.75 | | |
| Total | 39 | 1824.92 | | | |

Appendix 53: Analysis of variance for thousand seed weight of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 0.04173 | 0.01391 | 1.09 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 1.99837 | 0.22204 | 17.46 | <.001 |
| Residual | 27 | 0.34340 | 0.01272 | | |
| Total | 39 | 2.38350 | | | |

Appendix 54: Analysis of variance for head length of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 2.3994 | 0.7998 | 1.47 | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 382.5289 | 42.5032 | 77.98 | <.001 |
| Residual | 27 | 14.7172 | 0.5451 | | |
| Total | 39 | 399.6455 | | | |

Appendix 55 : Analysis of variance for head girth of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 3.220 | 1.073 | 0.76 | |
| REP.*Units* stratum | | | | | |

| | | | | | |
|---|---|---|---|---|---|
| TREATMENT | 9 | 524.687 | 58.299 | 41.27 | <.001 |
| Residual | 27 | 38.136 | 1.412 | | |
| | | | | | |
| Total | | 39 | 566.043 | | |



Appendix 56: Analysis of variance for head weight of pearl millet (Pennisetum glaucum [L.])

| Source of variation | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---|---|---|---|---|
| REP stratum | 3 | 2.365 | 0.788 | 0.47 | |
| | | | | | |
| REP.*Units* stratum | | | | | |
| TREATMENT | 9 | 600.787 | 66.754 | 39.77 | <.001 |
| Residual | 27 | 45.322 | 1.679 | | |
| | | | | | |
| Total | 39 | 648.474 | | | |