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Characterization Of Finger Millet [(*Eleusine coracana* (L.) *Gaertn*] Genotypes for their Agronomic and Nutritional Performance in Mashonaland East Province, Zimbabwe

Benjamin Chirambiwa; Everton Jaison; Sikhangezile Mbondiya; Nathan Sangombe
Ministry of Lands, Agriculture, Fisheries, Water and Rural Development
Molafwrd, Marondera . ZIMBABWE

Daiton Mawira
Corteva. Agronomist. Zimbabwe

Abstract:- Regardless of its ability to curb food and nutrition insecurity, finger millet has been overlooked in the mainstream of crop improvement research resulting in few varieties on the Zimbabwean market. Characterisation and improvement of available genotypes through research are needed to improve finger millet productivity. The study aimed to assess the agronomic and nutritional performance of 64-finger millet lines in the Mashonaland East Province of Zimbabwe. The experiment was carried out in the 2022/2023 summer season at two sites; Kushinga Phikelela Agricultural College and Grasslands Research Station. The experimental design used was the square alpha lattice with 8 blocks by 8 entries, four rows for each accession, replicated twice. The combined analysis showed a significant difference (P< 0.001) in eight out of the eighteen variables of the 64 genotypes. These included the number of days to 50% flowering, plant height, number of basal tillers, number of days to maturity, number of productive tillers, number of ears harvested per plant, 1000 seed weight and Ca concentration.

There was significant Genotype + Genotype x Environment interaction (GGE) in the number of ears harvested per plant and the number of days to 50% flowering (P< 0.001 and P< 0,005 respectively). The principal component analysis revealed that the first 9 components with an Eigen value of greater than 0.5010 contributed to about 91.9% of the total variability. Plant count per plot, plant height, basal tillers, productive tillers, 1000-grain weight, productive tillers per plant, days to maturity, per cent plant stand at harvesting, number of ears harvested per plant, number of ears harvested per plot, dry ear weight, grain yield, and biomass yield were the most important traits contributing to the overall variability thus showing great levels of genetic diversity. The researcher recommends the extension of the multi-locational trials to other agroecological regions of Zimbabwe for variety niche matching. Top performing genotypes, ICFV 192455, ICFV 192433, and ICFV 192420 should be improved and released for their grain yield and high calcium content.

Keywords:- *Finger Millet, Genetic Diversity, GGE Biplot, Principal Component Analysis.*

I. INTRODUCTION

Eleusine coracana (L.) Gaertn., commonly known as rapoko or finger millet is a C4, self-pollinated plant that belongs to the family Poaceae (Gramineae) (Katake *et al*., 2016). Its grains have a variety of sizes, colours, and forms, with brown being the most common. It is primarily grown for food, fodder, and medicinal purposes. It is a robust annual grass that is mostly grown as a staple cereal food crop in the world's tropical and subtropical regions of Africa, Asia, and South America under rainfed conditions (Upadhyaya *et al*., 2007). Finger millet is seen as a crucial cereal crop for food security (Kumar *et al*., 2016). It can be stored for years without being attacked by storage pests (Government of Zimbabwe, 2020).

There are hints that the cultivated gene pool variety was improved from the weedy and wild ancestor *E. africana* in Africa (Sood & Kalyana Babu, 2016). Finger millet makes up about 12% of the world's millet area (Kumar *et al*., 2016). Ethiopia, Kenya, Uganda, India, Nepal, and China are the world's top-finger millet producers. It originated from the highlands of Ethiopia and Uganda (Vidhate *et al*., 2020).+

Small-holder farmers are predominantly the producers of finger millet using a low-input approach (Kumar *et al*., 2019) resulting in low yields being achieved. Most farmers produce less than 1 tonne of grain per hectare, while the crop has a production potential of more than 6 tonnes per hectare (Upadhyaya *et al.*, 2007; Al-Khayri *et al*., 2019).

Finger millet is a “library” of stress tolerance genes that make it adapted to various abiotic factors including high levels of moisture stress and high temperatures (Kumar *et al*., 2019). Samundeswari *et al*., (2018), highlighted that

finger millet compared to other tropical cereals, can adapt to various agro ecological zones, higher elevations, and dry, and wet circumstances.

However, finger millet's low yield, the laborious nature of its processing, and the unfavourable stigma attached to it as a food for the underprivileged have all contributed to a drop in its adoption and consumption (Samundeswari *et al*., 2018). Lack of agronomic advice, a small genetic base and restricted research funding, all contribute to the genetic degradation of finger millet (Al-Khayri *et al*., 2019; Upadhyaya and Gowda, 2006).

The only four heavily subsidized and industrialized crops; maize, rice, soyabeans, and wheat, make up more than 60% of the calories consumed by humans worldwide (Patil *et al.* 2019. This is an issue because a person's daily calories come from unnutritious foods. Whole foods from finger millet tend to give a wealth of important essential micronutrients with few calories such as calcium (Upadhyaya and Gowda, 2006).

Finger millet may contribute to nutritional security since it has a high nutritional value (Chethan & Malleshi, 2007). Patil *et al*. (2019), reported that the protein content in finger millet grain ranges from 5.6 to 12.7%, and it is substantially larger in brown-seeded genotypes than in white-seeded ones. The essential amino acids, tryptophan, threonine, lysine, methionine, valine, and isoleucine are abundant in its proteins (Patil *et al*., 2019). Additionally, finger millet grain is rich in minerals (2.5–3%), like calcium (310–370 mg/100 g), potassium, iron, zinc, sulphur, and manganese, as well as B complex vitamins like niacin, B6, and folic acid (Ramashia *et al*., 2019). Its seeds are a good source of dietary fibres (2.5–3.5%), fat (1–1.5%), carbohydrates (65–75%) and sugars (Kumar *et al*., 2019; Kumar *et al*., 2016; Al-Khayri *et al*., 2019). Additionally, it contains a lot of polyphenols. The fibre in finger millet grains has various health benefits that include preventing intestinal cancer, excessive cholesterol, and constipation (Patil *et al*., 2019; Kumar *et al*., 2016; Devi *et al*., 2014). Furthermore, the crop is said to have anti-ulcerative, hypocholesterolemic, and hypoglycemic qualities.

Given the above, more work is needed to support finger millet breeding to bridge the gap between farmer output and actual yield potential given the significance of finger millet to smallholder farmers in the semi-arid regions of Africa, Asia, and Zimbabwe in particular.

Because of these benefits derived from finger millet, it is necessary to characterise the variation within its various genotypes and produce data on the crop traits that matter economically to support breeding efforts (Kumar *et al*., 2017). The genetic resources must be characterised to be used effectively in crop improvement initiatives. This study makes an effort to characterise and assess the agronomic and nutritional performance of finger millet lines obtained from the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, Zimbabwe) in the Mashonaland East province of Zimbabwe.

A. Statement of the Problem

The availability of improved finger millet varieties for farmers is hampered by a lack of all-inclusive characterisation of finger millet genotypes. It is difficult to attain high finger millet yields without access to improved varieties. Identifying and selecting superior variants for cultivation might be difficult without a solid understanding of the genetic diversity and traits of various finger millet genotypes. This study attempts to fill this gap by thoroughly characterising the genotypes of finger millet, including their agronomic, and nutritional traits. The research aids in the improvement of finger millet varieties, and crop management techniques, and help in ensuring food and nutritional security in arid and semi-arid regions of the world and Zimbabwe in particular.

B. Justification of the study

Farmers are currently cultivating low-yielding finger millet cultivars that are highly vulnerable to various biotic and abiotic stresses. In Zimbabwe, few improved finger millet varieties are found on the market (Government of Zimbabwe, 2020). More so, the crop's potential for improvement is constrained by the lack of information about the available germplasm information (Government of Zimbabwe, 2020). Numerous agronomic traits like tillering ability, plant height, plant pigmentation, panicle length and width, days to harvest maturity, days to 50% flowering, ear size, discontinuity of spikelet, grain colour, and blast disease resistance, have been linked to extensive genetic diversity, particularly among landraces. However, this variation is still poorly understood, unexploited, and underutilized (Al-Khayri *et al*., 2019; Oduori, 2005; Upadhyaya *et al*., 2008). Although only modest attempts have been performed in the past, efforts to mine the existing genetic variation among available genotypes to improve cultivated finger millets are worthwhile. Characterisation and evaluation are crucial prerequisites for the efficient use of germplasm as well as the discovery of sources for beneficial genes. (Vidhate *et al*., 2020; Ulaganathan & Nirmalakumari, 2011).

C. Objectives of the study

➢ *General objective*

To characterise and assess the agronomic and nutritional performance of sixty-four finger millet lines in the Mashonaland East province of Zimbabwe to support breeding efforts towards the production of finger millet varieties that have farmer-desired traits.

➢ *Specific objectives*

- To phenotypically characterise finger millet lines from ICRISAT in Mashonaland East province.
- To assess the yield potential of the sixty-four finger millet lines.
- To determine the nutrient content (calcium and iron) of the sixty-four lines using X-ray fluorescence spectrometry (XRF spectrometer).

D. Hypotheses

- There is no variation in the sixty-four finger millet lines.
- There is no difference in the yield potential of the sixty-four lines.
- The sixty-four lines have the same nutrient content (calcium and iron) levels.

II. LITERATURE REVIEW

This chapter is a review of finger millet and its origin, the economic importance of finger millet, the constraint of its production by farmers, its diversity as well as its agronomic and nutritional performance. A review of methods of data analysis associated with the chosen type of experimental design will be discussed.

A. Finger millet and its origin

The name "Finger Millet" comes from its panicle's finger-like branching. After sorghum, *(Sorghum bicolor)*, pearl millet *(Pennisetum glaucum)*, and foxtail millet *(Setaria italica)*, it is the fourth most important millet crop in the world (Vidhate *et al*., 2020). Finger millet comes in sixth position among cereals and millets in terms of production after wheat, rice, maize, sorghum, and bajra (Anuradha & Patro, 2019). It is a self-pollinated crop that originated from the Ethiopian Highlands in Central Africa. The crop is an annual grass that belongs to the Graminae or Poaceae family (Vidhate *et al*., 2020).

B. Economic importance of finger millet.

Finger millet is a staple food crop in regions of the world that are prone to drought and is seen as a critical element of food and nutritional security (Phiri *et al*., 2019). Its grain is an ideal food grain commodity for famine-prone locations as it has low or little post-harvest losses through storage pests hence it can be stored for years (Phiri *et al*., 2019). It is a crucial crop used for food, forage, and industrial products. The sprouted grains are utilized to manufacture liquor and the by-products are fed to livestock. Phiri *et al.*, (2019), reported that although grains are consumed by humans, the crop stover is used as stock feed, particularly during the dry season. Finger millet straw contains up to 61% of the total amount of digestible elements (Phiri *et al*., 2019).

C. Finger millet characteristics

The drought-tolerant finger millet crop can represent an important crop for future human usage. It thrives in areas with irregular weather patterns, little to no consistent rainfall, and nutrient-poor soils (Muzerengi & Tirivangasi, 2019). Finger millet can withstand harsh weather conditions and quickly recover from biotic and abiotic challenges. It is generally the most drought-tolerant cereal grain crop requiring little input during growth and performs better in dry regions with decreasing water supplies (Luke, 2020). It is a resilient crop that can produce a respectable grain yield while others like maize produce no or very insignificant yield (Keba *et al*., 2022). Identifying better-performing finger millet genotypes should be prioritised.

Together with sorghum and pearl millet, finger millet is a critical candidate for climate-smart agriculture and a strategic adaptation option in the face of climate change in Zimbabwe. Recurrent climatic changes in Zimbabwe will cause adjustments in agroecological regions, as high temperatures are predicted to decrease the growing season by 2 to 35 days (Sakadzo & Kugedera, 2020). By the year 2080, Zimbabwe will be classified as a non-maize producing zone due to climate change, a situation that would increase food insecurity (Sakadzo & Kugedera, 2020). Therefore, research should be directed towards the improvement of the "future grain for Africa"; the indigenous grains, particularly finger millet.

Since maize is currently the staple food crop, adaptation strategies should be introducing indigenous grains (sorghum, millet, and finger millet) to improve food security in response to climate change. The poor and vulnerable will be most affected by climate change, particularly smallholder farmers who depend on rain-fed agriculture for a living. Climate change is predicted to cause a net 3.2% drop in Sub-Saharan Africa's cereal production by 2050 (Sakadzo & Kugedera, 2020). Finger millet is preferable to other cereals since it has exceptional tolerance to drought, and has longer-term yield stability.

According to Phiri *et al*., (2019), finger millet requires an average of 400 mm of rainfall during the growing season, while maize requires at least 500 mm for its growing season. Finger millet can be produced with minimum inputs as compared to other cereals. Due to its ability to withstand heat, salt, and water stress, finger millet is a good crop for semi-arid and arid regions (Phiri *et al*., 2019).

D. Nutritional importance of finger millet

Enhancing the productivity of these climate-smart crops might lessen poverty and increase food and nutritional security in Zimbabwe. According to the study findings by Muzerengi & Tirivangasi, (2019), it was shown that finger millet boosts food availability, accessibility, utilisation, and stability, making its production a reliable adaptation strategy to climate change.

The crop has nutritional potential that is comparable to common cereals like maize, rice, wheat, barley, or bajra in terms of protein, carbohydrate, and calorie levels (Kumar *et al*., 2016). In addition, it supplies minerals, and essential amino acids, particularly methionine, which is deficient in the diets of many underprivileged people who eat a lot of starchy foods.

According to Devi *et al*. (2014), finger millet has roughly 5-8% protein, 1-2% ether extractives, 65-75% carbohydrates, 15-20% dietary fibre, and 2.5-3.5% minerals. It contains key essential amino acids; tryptophan, methionine, threonine, valine, isoleucine and cysteine which are required for good health (Patil *et al*., 2019). It is low in fat content (1.3%) and the majority is unsaturated fat. Among all cereals, it contains the highest calcium content (344 mg/100 g), which is five to thirty times more than other cereals. Calcium is essential for good bone growth and it

fights against osteoporosis. Potassium, iron, and phosphorus, all aid in the treatment of anaemia (Devi et al., 2014).

The grain is gluten-free, hence recommended to gluten-sensitive people. The seed coat of finger millet has a high concentration of nutraceuticals (phytochemicals) such as polyphenols and dietary fibre (0.2–3.0%). Dietary fibre helps in reducing weight. It is now well-established that phytates, polyphenols, and tannins can help millet foods' antioxidant activity, which is a crucial component in maintaining good health, slowing the ageing process, and preventing metabolic illnesses (Devi *et al*., 2014).

Due to their importance in supporting bodily processes and health throughout adulthood and later stages of life, polyphenols are also known as "Life span essentials"; they extend one's life span (Devi *et al*., 2014). The polyphenols have characteristics like antioxidant, anti-mutagenic, anti-oestrogenic, anti-carcinogenic, and anti-inflammatory effects, antiviral effects and platelet aggregation inhibitory activity that may be useful in preventing or reducing the incidence of diseases in humans (Devi *et al*., 2014). It boosts the physical health of the elderly, the ill, children, the pregnant and nursing women since it contains more health nutrients than maize, wheat, and rice (Nciizah *et al*., 2020).

Consuming finger millet frequently helps to maintain glucose homeostasis and prevents unhealthy levels of lipids (dyslipidemia) in the body. A meal made from finger millet requires less flour to prepare than a meal made from maize, and it provides more energy as well as satiates the hunger for a longer period (Nciizah *et al*., 2020; Phiri *et al*., 2019). Epidemiological research has shown that frequent eating of whole grain finger millet and its by-products can reduce the risk of gastrointestinal malignancies, type II diabetes, cardiovascular diseases, and a variety of other ailments (Devi *et al*., 2014).

The nutritional and health benefits of finger millet are provided by the concentrated dietary fibre, minerals, phenolics, and vitamins found in the seed coat or outer layer of the grain because millets are often prepared from the complete grain (Devi *et al*., 2014).

Given all of these advantages for health, finger millet is referred to as a "super cereal" or "nutria cereal" (Devi *et al*., 2014). This necessitates the research and study of the crop to promote its adoption by many farmers for its health benefits. Nutritious and high-yielding finger millet cultivars are required for adoption and profitability.

E. Main reasons for low adoption and reduced finger millet production in Zimbabwe

Despite the enormous potential of finger millet to offer food and nutrition security for countries in arid and semi-arid regions and its workable strategy for coping with climate change, its adoption among farmers is still alarmingly low as a result of several reasons herein discussed.

The unavailability of improved finger millet varieties on the market is one important factor contributing to the low uptake of finger millet production. Where improved seed is available, it is expensive and farmers cannot buy it. Farmers rely excessively on previous-season-retained and untreated seed which significantly lowers yields (Muzerengi & Tirivangasi, 2019; Sakadzo & Kugedera, 2020). Research on finger millet has lagged in Zimbabwe since maize is frequently preferred as the main crop.

Although finger millet is essential to the livelihoods and security of food and nutrition of resource-constrained farmers and consumers in impoverished nations, finger millet is regarded as an orphan crop by the international scientific community (Muzerengi & Tirivangasi, 2019). There is a need for significant investment from the public and private sectors in the research and development of high-yielding and nutrient-dense finger millet varieties that taste better than maize, rice and wheat (Phiri *et al*., 2019). The improved varieties should be availed on the market for easy access by farmers.

Finger millet production is extremely labour-intensive, requiring careful field preparations, weeding, wild bird scaring, harvesting, and grain processing. Generally, there is no equipment or technology available in Zimbabwe to harvest, thresh, winnow, dehull and process finger millet into edible products. All operations are done manually making them very tedious, labour-intensive and deterrent enough to farmers. Rapoko grass *(Eleusine indica)* is difficult to distinguish from the crop, making weeding very difficult. There is no technology in place to stop quelea birds from damaging the crop leaving farmers resorting to doing it physically, a time-consuming situation (Phiri *et al*., 2019; Muzerengi & Tirivangasi, 2019). Genotypes that are easy to manage and process and those that are resistant to quelea bird damage need to be identified and released into the market.

Over-reliance on the staple crop; maize, as the sole source of food, when in fact, it has a very high risk of failure in arid and semi-arid regions is one factor contributing to low finger millet production by farmers (Muzerengi & Tirivangasi, 2019). Developing and promoting improved finger millet varieties is the solution to this problem.

The Zimbabwean government has been providing farmers with subsidized or free maize seed and fertilizer inputs but the maize crop failed since it cannot stand the unpredictable and unfavourable climatic conditions inherent in the arid and semi-arid areas of the country (Phiri *et al*., 2019). It is effort directed to the wrong crop. Farmers accept the maize inputs because they don't have a choice. There is little government support for research, growing, processing, and usage of finger millet despite earlier research showing that climate-smart grains outperform maize in these semi-arid environments. Farmers are deterred from growing finger millet by a lack of incentives, subsidies, storage options, and efficient transportation methods (Phiri *et al*., 2019). Enhanced finger millet research support can be an

alternative solution to the food insecurity situation in the country.

Ignorance among many farmers about the health benefits of consuming finger millet has contributed to low production and low uptake of the crop, hence the need to provide information through various ways like awareness campaigns through the partnership of different stakeholders. This will increase the market acceptance of higher-yielding, better-tasting finger millet cultivars and their use as a climate change adaptation strategy (Muzerengi & Tirivangasi, 2019).

In addition to the above, the inherently lower grain yields of finger millet (0.5 to 2t/ha) compared to maize (8t/ha), low producer prices, susceptibility to quelea birds and changing consumer food preferences have been the major challenges in the adoption and production of the crop in the country (Muzerengi & Tirivangasi, 2019). There has also been a lack of extension services which contributed to the low yield of these small grains.

The lack of a vibrant market for finger millet for farmers is another impediment to its production. Unlike the typical export crops like tobacco, cotton, and seed maize, the concept of exporting finger millet is not even on the table (Muzerengi & Tirivangasi, 2019). To stimulate finger millet production, policies that support the development of competitive intra-rural markets must be implemented. This will enable it to be grown both as a cash crop to meet other financial demands as well as for subsistence household food security. An associated identification and improvement of high-yielding finger millet varieties is necessary to satisfy the market.

Currently, less than 10% of Zimbabwe's total production of indigenous grains is sold on the formal market in Zimbabwe (Phiri *et al*., 2019). The majority is either consumed by the households that produce them or is sold in the black markets, primarily for the manufacturing of traditional beer. There are no attractive market incentives for smallholder farmers who grow finger millet (Muzerengi & Tirivangasi, 2019).

With the above discussion in mind, it is indispensable that research, government policy, and non-governmental organization aid programs on food crop production in Zimbabwe should direct their efforts toward the promotion of finger millet production rather than maize in these semi-arid areas. New solutions to small grains value chains in Zimbabwe should be anchored on having unrestricted access to improved finger millet varieties, improved equipment and processing techniques, enhanced post-harvest management and improved market access for both inputs and outputs (Muzerengi & Tirivangasi, 2019).

F. Genetic diversity and agronomic performance of finger millet.

Finger millet has been overlooked in mainstream crop improvement research despite its acknowledged usefulness as a potential and significant staple crop, particularly for poor populations in arid and semiarid locations (Sood & Kalyana Babu, 2016). Its improvement can be accelerated by the exploitation of critical agro-morphological traits, with a focus on improving the locally well-adapted genotypes for the creation of stress-tolerant, high-yielding varieties with enhanced nutritional qualities. Finger millet cultivars with yields that are twice as high as they are now can be developed quickly by combining conventional and molecular breeding approaches (Sood & Kalyana Babu, 2016). For optimal management and use of finger millet landraces and genotypes, genetic diversity knowledge is essential. Various molecular markers have been extensively employed in finger millet for identification, and genetic diversity analysis.

According to Suman, *et al*. (2019), the most significant polygenic variables that contribute to the overall variability are grain yield per plant, 1000-grain weight, and productive tillers per plant, days to flowering, days to maturity, finger number per panicle, finger length, and finger width. These traits should be prioritized in the improvement program for finger millet (Suman *et al*., 2019).

Studies on diversity have made extensive use of morphological descriptors, which comprise qualitative or quantitative traits detected in accessions of finger millet and most closely related wild species (Heather and Joanna, 2011). Qualitative characteristics such as plant pigments, growth habits, inflorescent compactness, grain colour, lodging, and plant appearance are descriptors used to characterize the germplasm of finger millet (Heather and Joanna, 2011).

Quantitative traits include the number of days to 50% flowering, plant height, and the number of basal tillers and culm branches on each plant. Other important quantitative traits are the size of the flag leaf and its sheath, the length of the peduncle, the size of the inflorescence, the size of the longest finger, and the number of panicles on each plant (Heather and Joanna, 2011).

Literature has reported the performance of finger millet in many agronomic traits that include the number of tillers (2-40), number of days to 50% flowering (68- 103 days), plant height (53 -170cm), number of days to maturity (105 – 146 days), number of ears per plant (17-26), grain yield (500 - 3540 kg/ ha), 1000 grain weight (up to 3.29g), biomass yield (5.210 -10.700 t ha^{-1}) (Aparna *et al*., 2020; Leku, 2020; Hebbal *et al*., 2018; Backiyalakshmi *et al*., 2021; Umar & Kwon-Ndung, 2014; Keba *et al*., 2022). Most of these traits complement each other to produce dry matter, for example, plant height, leaf area, and tiller number (Aparna *et al*., 2020).

However, according to Wafula *et al*. (2016), finger millet has the potential to attain 5 to 6 tonnes ha^{-1} under perfect irrigation circumstances. In a prolonged good season yields of 4.738t ha^{-1} were achieved (Wafula, et al., 2016). African genotypes were discovered to flower later, with taller plants, fewer tillers, and more stover than Asian accessions (Backiyalakshmi *et al*., 2021).

An essential link between protecting and using plant genetic resources is germplasm identification in the finger millet plant. To overcome the negative challenges brought on by biotic and abiotic stress, the usefulness of germplasm in the study of plant genetic resources may play a significant role in the development of new hybrids and high-yielding crop types with disease-resistant features. The genetic relatedness between these species may be revealed through phenotypic characterisation. This will help with the exploration of new species and the comprehension of genetic diversity. This might reveal details on the ecology and taxonomy of the plant (Umar & Kwon-Ndung, 2014).

Even though morphological descriptors are heavily influenced by the environment, their precise estimates demonstrate the expression of adaptive genes that, if maintained, increase the capacity for evolution and local adaptability to changing environmental conditions (Heather & Joanna, 2011).

On a variety of crops, including chickpea, pearl millet, proso millet, and wild ginger, a sizable number of morphological-based diversity studies have been carried out (Heather and Joanna, 2011). Numerous finger millet accessions of both African and Indian origins exhibit great morphological variation, according to reported characterisation studies (Upadhyaya *et al*., 2009). As a result, using morphological descriptors to estimate phenotypic variability within a germplasm collection is an efficient approach towards finger millet improvement (Heather & Joanna, 2011).

Exploiting genetic variability for economic features is essential for a plant breeder to create high-yielding cultivars. A breeder must be aware of both the heritability of the desired features and the diversity of the current gene pool to generate very productive varieties (Anuradha & Patro, 2019). Despite being a food security crop, being highly nutritious, and being native to Africa, finger millet has only drawn a small amount of financial and scientific interest as mentioned earlier (Heather & Joanna, 2011).

G. Alpha lattice design.

The genetic effect in genotypes is inferred from data collected on their phenotypic expression, therefore, selecting a suitable experimental design is essential when characterising genotypes (Khan *et al*., 2015). The goal of the experiment, the type of trial, the size of the treatment, the number of elements to be studied, the accessibility of facilities for the experiment, and the slope and shape of the land to be used are just a few of the variables that influence the choice of an appropriate experimental design to use (Akinwale *et al*., 2021). Completely randomized design (CRD), randomized complete block design (RCBD), latin square design, and factorial designs (split plot and strip plot) can only be used when the treatment size is not too large as their effectiveness decreases with an increase in the number of treatments (Akinwale et al., 2021).

RCBD should be substituted with alpha lattice in any agricultural field studies when the number of treatments to be evaluated rises above ten (Khan *et al*., 2015; Akinwale *et al*., 2021). Unlike the CRD, which is common in laboratory trials, the alpha lattice design accounts for additional sources of variation such as soil heterogeneity, plant-to-plant competition, and climatic factors that might amplify the impacts of treatment (Akinwale *et al*., 2021).

Under field circumstances, alpha lattice design offers better control over experimental variability among the experimental units and improves the precision level by lowering the mean square error, coefficient of variation, and standard error of difference (Khan *et al*., 2015; Akinwale *et al*., 2021; Ismail *et al*., 2018). The alpha lattice design minimizes bias, and is more accurate and efficient at reducing experimental error, demonstrating its outstanding capacity to identify the importance of minute variations in genotype means (Ismail *et al*., 2018).

It allows the capture of variations not related to the treatment being studied, which will inevitably skew the choice of whether to reject or fail to reject the null hypothesis. It aids the scientist in avoiding making any statistical errors, namely Type I or Type II errors (rejecting a true null hypothesis is a type I error and failing to reject a false null hypothesis is the type II error). This is the rationale behind the application of alpha lattice designs in most plant breeding trials.

Due to its practicality, adaptability, and versatility, the partially balanced lattice design has been utilized more frequently than the balanced (square) lattice design. Contrarily, the balanced (square) lattice is constrained by stringent rules and regulations that make it less feasible in terms of land availability, the usage of a large number of seeds for testing, and the high expense of testing. A perfect square of genotypes, like 25, 36, 49, 64, and so forth, must make up the total number of genotypes to be examined. These issues make the square alpha lattice design unpopular (Akinwale *et al*., 2021).

H. Cultivar stability assessment and multivariate analysis.

Plant improvement entails concurrently modifying genetic traits to maximize productivity in light of the constraints imposed by environmental conditions (Zakir, 2011). Multivariate statistical techniques that simultaneously analyse multiple measurements on the genotypes under investigation are frequently used in the analysis of genetic diversity, genotype performance and the classification of germplasm collections (Suman *et al*., 2019). When introducing varieties for certain cropping environments, the adaptability and stability of a genotype are useful considerations (Zakir, 2011).

According to Pour-Aboughadareh *et al*., (2022), genotype * environment interaction (GEI) is a multiplicative effect that results from the interaction between genotype and environment in addition to the additive effect of genotype (G). The genotype by environmental interaction (GEI) can be spatial (location-based), temporal (years/ season) or both

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factors (Pour-Aboughadareh *et al*., 2022). A collection of genotypes can be evaluated in multi-environment trials (METs) to recommend them for specific habitats and define mega-environments. METs make it easier to find genotypes with low variability or those that are consistent across several sites (Ebem *et al*., 2021).

There are two categories of GEI: (i) crossover or qualitative interaction and (ii) non-crossover or quantitative interaction (Pour-Aboughadareh *et al*., 2022). Crossover interaction is when genotype rankings shift from one environment to another. Non-crossover interaction is when there are variations in the magnitude of genotype performance across different environments without a change in the rank order of genotypes. A stable genotype's performance is not affected by the environment and it can predictably respond to an environment (Ebem *et al*., 2021).

A graphical tool that expertly aids breeders in interpreting the GEI in MET trials is the Genotype + Genotype * Environment (GGE) biplot approach. Pour-Aboughadareh *et al*., (2022) report that GGE biplots can be used for different analyses. They are used to give test genotypes a ranking pattern based on their yield performance in any given environment. They give test environments a ranking pattern based on the relative yield performance of any given genotype. They are also used to compare the yield performance of any given pair of genotypes across environments (Pour-Aboughadareh *et al*., 2022). It is possible to identify the top genotype(s) in each test environment and determine potential mega-environments based on the top genotype using the GGE biplots. Stable and average performance genotypes can simultaneously be investigated using GGE biplots. The discriminating ability and representativeness power of test environments can also be easily determined using GGE biplots (Pour-Aboughadareh *et al*., 2022; Khan *et al*., 2021)

Principal component analysis (PCA) and cluster analysis have also been proven to be among the most effective multivariate techniques for choosing genotypes for breeding programs that satisfy a plant breeder's goal. According to Suman *et al*., (2019), PCA can be used to identify patterns and remove redundancy in data sets. The study of genetic diversity and the creation of core subsets for classifying accessions with comparable characteristics into a single homogenous category are two common applications for cluster analysis. In numerous crops, including finger millet, multivariate analysis has been employed frequently for genetic diversity studies (Suman *et al*., 2019). Breeding trials sometimes involve many conditions to find high-yielding lines or clones that are stable across and within environments. Due to variations in soil types, weather (precipitation, temperature, radiation, evaporation, among others), and management (fertility levels and levels of protection against pests and diseases), multi-environment trials (MET) are vulnerable to high levels of GEI.

The goal of this study is to gather data on the diversity of finger millet lines at morphological and nutritional levels and to examine the potential of the genotypes for crop improvement in yield potential and nutrient density among other variables in the Mashonaland East province of Zimbabwe. The diversity of the germplasm would be characterised to produce information that breeders might use to effectively support breeding efforts. Research in finger millet will go a long way in contributing to the food and nutrition of the country.

III. MATERIALS AND METHODS

A. Description of study sites

The research was carried out on two sites in Mashonaland East Province, at Kushinga Phikelela Agricultural College and Grasslands Research Station. Both sites are located in the Marondera district. The district lies in Natural Region IIb, with an annual rainfall of 750 mm-1000 mm and a temperature range of 20^0C – 30^0C. The district's altitude is 1688m. Specific site descriptions are shown in Table 1.

Table 1: Description of the study site

SITE	Annual rainfall	Soil type	GIS codes	pH	Natural Region
Kushinga Phikelela Agricultural College	750-1000 mm	Clay -loam	-18.1550S; 31.6670 E	4.5-6.5	IIb
Grasslands Research Station	750-1000 mm	Sandy loam	-18.1780S; 31.5020 E	4.5	IIb

B. Treatments

The experiment used 64 genotypes of germplasm chosen from ICRISAT Zimbabwe collections. They were originally collected from East Africa, Central Africa and Southern Africa in countries like Tanzania, Kenya, Zambia, Malawi, and Zimbabwe. Their nomenclature is in the form of codes like ICFV 192455, ICFV 192430, and ICFV 192411 and so on. Each of the sixty-four germplasms were planted in 2m by 4 rows with interrow spacing of 0.5m and in-row spacing of 0.15m.

C. Experimental design

The sixty-four genotypes were planted in a square alpha lattice design with 8 blocks by 8 entries, four rows for each accession, and two replications for the evaluation, which lasted from January 2023 to May 2023. The spacing was 0.5m × 0, 15 m, inter-row and in-row respectively. The gross plot size was $3m^2$ and the net plot will be $1m^2$. The blocks were separated by a distance of 1m and the entries by 0.5m.

D. Trial Management

The land was ploughed, disced and levelled. Planting farrows were made accordingly. Planting was done in the first week of January 2023. Basal fertiliser (250kg/ha Compound D) was applied and incorporated. Lime at 1000kg/ha and gypsum at 200kg/ha were applied. During field planting, the seed was manually sown in rows to guarantee proper germination. Three weeks after emergence, seedlings were thinned to a plant density of 133 333 plants /ha. At four and eight weeks after planting, top dressing fertiliser (Ammonium Nitrate at 250kg/ha) was split applied respectively. Weeding was done whenever necessary.

E. Data Collection

The data was collected on the traits shown in Table 3.5.1. Standard finger millet descriptors (Suman et al., 2019) were used to determine and record morphological features as shown in Table 2.

Table 2: Data Collection measurements

Traits	Units	Measurement
Plant stand	Count	Counting the number of plants per plot after thinning
Seedling vigour	Score	Scoring seedling vigour on a 1-5 scale
Days to flowering	Count	Counting the number of days taken to reach 50% flowering
Disease pressure	Score	Visual assessment and scoring on a 1-9 scale
Pest pressures	Score	Visual assessment and scoring on a 1-9 scale
Basal tillers	Count	Counting the number of basal tillers per plant
Productive tillers per plant	Count	Counting the number of productive tillers per plant
Plant height	cm	Measuring from ground level to the tip of a mature plant
Lodging incidence	Score	Scoring the extent of lodging on a 1-5 scale
Number of days to maturity	Count	Counting the number of days taken by the plant to reach maturity
Number of plants per plot at harvest	Count	Counting the number of plants per plot at harvesting
Ears harvested per plot	Count	Counting the number of ears harvested per plot
Biomass yield	t/ha	Drying and weighing the biomass per plot
Dry ear weight	kg	Drying and weighing the ears
1000 grain weight	kg	Drying, counting 1000 grains and weighing
Yield per plot and ha	g/plot, t/ha	Drying and weighing the grain
Nutrient content	%, mg/100g	Measuring calcium and iron using X-ray fluorescence spectrometry (XRF spectrometer)

F. Data analysis

Data for eighteen variables from each of the two sites was subjected to combined Analysis of Variance (ANOVA) using GenStat 17th edition. ANOVA for each site was also conducted. The variables that showed significant differences had their means separated using the Fishers test at a 5% level of significance ($p \leq 0.05$). Principal component analysis and Genotype + Genotype * Environment (GGE) biplot analysis were also conducted to compare the agronomic and nutritional performance of the 64 genotypes.

IV. RESULTS

This section looks at the analysis of variance results, the principal component analysis results and the GGE biplot analysis results. Crop improvement depends on genetic variability research and using it for breeding by selecting the right lines. Determining the extent to which a character is influenced by its environment is also essential (Anuradha & Patro, 2019). The combined Analysis of variance for the eighteen variables is shown in Table 3.

Table 3: Combined finger millet agronomic and nutritional performance analysis results for the two sites.

	Number of days to 50% flowering		Basal tillers		Productive tillers		Plant height		Number of days to maturity		Number of ears harvested/ plant		1000 Seed weight		Ca Concentration	
	Gen	Days	Gen	Tillers	Gen	Tillers	Gen	(cm)	Gen	Days	gen	Ears	Gen	(g)	Gen	(ppm)
Minimum		66.00		1.375		1.125		30.25		118.0		1.875		1.760		3713
Maximum		97.00		14.38		9.625		84.00		146.0		21.50		2.820		8919
Grand mean		82.56		5.023		3.966		60.45		133.6		5.208		2.332		5295
	ICFV 192401	72.0^{a}	ICFV 192415	3.0^{a}	ICFV 192415	2.5^{a}	ICFV 192452	41.3^{a}	ICFV 192426	121.5^{a}	ICFV 192410	3.2^{a}	ICFV 192454	1.99^{a}	ICFV 192446	3953^{a}
	ICFV 192420	73.0^{ab}	ICFV 192444	3.7^{ab}	ICFV 192444	2.6^{a}	ICFV 192439	43.1^{ab}	ICFV 192398	123.0^{ab}	ICFV 192447	3.5^{ab}	Local Check	2.0^{ab}	ICFV 192436	4219^{ab}
	ICFV 192426	74.0^{abc}	ICFV 192401	3.8^{ab}	ICFV 192419	2.8^{a}	ICFV 192451	45.6^{abc}	ICFV 192431	123.2^{abc}	ICFV 192435	3.6^{ab}	ICFV 192451	2.1^{abc}	ICFV 192435	4237^{abc}
	ICFV 192429	74.3^{abc}	ICFV 192395	3.8^{ab}	ICFV 192395	3.0^{ab}	ICFV 192450	46.6^{abcd}	ICFV 192415	127.0^{abcd}	ICFV 192408	3.7^{ab}	ICFV 192441	2.1^{abc}	ICFV 192402	4339^{abcd}

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	ICFV 192431	74.5^{abcd}	ICFV 192423	3.8^{ab}	ICFV 192408	3.1^{ab}	ICFV 192429	47.3^{abcde}	ICFV 192444	127.2^{abcde}	ICFV 192444	3.7^{ab}	ICFV 192397	2.1^{abcd}	ICFV 192416	4431^{abcd}
	ICFV 192453	83.0^{bcdefghijklm}	ICFV 192433	4.7^{ab}	ICFV 192445	3.7^{abc}	ICFV 192405	60.4^{abcdefghijklm}	ICFV 192395	133.2^{abcdefg}	ICFV 192400	4.5^{abc}	ICFV 192431	2.3^{abcdef}	ICFV 192440	4986^{abcdefg}
	ICFV 192422	83.3^{bcdefghijklm}	ICFV 192441	4.7^{ab}	ICFV 192403	3.8^{abc}	ICFV 192442	60.5^{abcdefghijklm}	ICFV 192455	133.5^{abcdefg}	ICFV 192437	4.5^{abc}	ICFV 192418	2.3^{abcdef}	ICFV 192428	4998^{abcdefg}
	ICFV 192407	84.0^{cdefghijklm}	ICFV 192399	4.8^{ab}	ICFV 192420	3.8^{abc}	ICFV 192411	60.8^{abcdefghijklm}	ICFV 192437	133.8^{abcdefg}	ICFV 192394	4.6^{abc}	ICFV 192406	2.4^{abcdef}	ICFV 192411	5030^{abcdefgh}
	ICFV 192425	84.0^{cdefghijklm}	ICFV 192448	4.8^{ab}	ICFV 192399	3.8^{abc}	ICFV 192416	62.0^{abcdefghijklm}	ICFV 192403	135.0^{bcdefg}	ICFV 192428	4.6^{abc}	ICFV 192410	2.4^{abcdef}	ICFV 192413	5044^{abcdefgh}
	ICFV 192427	84.0^{cdefghijklm}	ICFV 192436	4.8^{ab}	ICFV 192424	3.8^{abc}	ICFV 192437	62.3^{bcdefghijklm}	ICFV 192424	135.0^{bcdefg}	ICFV 192436	4.6^{abc}	ICFV 192426	2.4^{abcdef}	ICFV 192405	5062^{abcdefgh}
	ICFV 192410	88.0^{klm}	ICFV 192438	6.9^{bc}	ICFV 192439	5.3^{abc}	ICFV 192419	71.5^{ijklm}	ICFV 192456	139.0^{defg}	ICFV 192439	8.0^{bcdef}	ICFV 192446	2.5^{bcdef}	ICFV 192401	6477^{defgh}
	ICFV 192396	88.3^{lm}	ICFV 192439	7.0^{bc}	ICFV 192449	5.75^{bc}	ICFV 192424	72.7^{jklm}	ICFV 192396	139.5^{efg}	ICFV 192454	8.8^{cdef}	ICFV 192405	2.5^{cdef}	ICFV 192433	6665^{efgh}
	ICFV 192435	88.3^{lm}	ICFV 192456	7.2^{bc}	ICFV 192456	5.87^{bc}	ICFV 192403	73.7^{klm}	ICFV 192434	140.5^{fg}	ICFV 192398	10.0^{def}	ICFV 192425	2.6^{def}	ICFV 192420	6796^{fgh}
	ICFV 192447	88.5^{lm}	Local Check	7.3^{bc}	Local Check	5.9^{bc}	ICFV 192422	74.9^{lm}	ICFV 192412	142.0^{g}	Local Check	10.3^{ef}	ICFV 192440	2.6^{ef}	ICFV 192455	7071^{gh}
	ICFV 192412	89.3^{m}	ICFV 192449	10.1^{c}	ICFV 192438	5.96^{c}	ICFV 192396	76.2^{m}	ICFV 192410	142.2^{g}	ICFV 192449	12.2^{f}	ICFV 192433	2.7^{f}	Local Check	7243^{h}
LSD		6.838		2.427		1.928		9.793		8.216		3.072		0.328		1043.7
CV%		4.2		24.4		24.6		11.6		3.1		29.8		7.1		14.1
S.e.d		3.455		1.226		0.974		4.949		4.152		1.552		0.166		527.5
Sig.	Genotype	<.001***		<.001***		<.001***		<.001***		<.001***		<.001***		<.001***		<.001***
	Site	<.001***		<.001***		<.001***		<.001***		<.001***		<.001***		0.068		<.001***
	Gen*Site	0.003**		0.012		0.118		0.019		0.013		<.001***		0.137		0.154

Key: Means that do not share a letter are significantly different and the top five, middle five and bottom five performance means of the 64 genotypes were computed. Gen = Genotype, **, ***= significance at P<0.05 and P< 0.01 respectively.

The mean performance of finger millet at both the Kushinga Phikelela Agricultural College site and Grasslands Research Station sites showed a significant difference (P< 0.001) in eight variables of 64 genotypes (Table 3). These included the number of days to 50% flowering, plant height, number of basal tillers, number of days to maturity, number of productive tillers, number of ears harvested per plant, 1000 seed weight and Ca concentration. The rest of the variables did not show any significant difference.

The late flowering genotypes were ICFV 192412, ICFV 192447, ICFV192396, and ICFV 192435,Those that flowered early were ICFV 192401, ICFV 192420, ICFV192426, and ICFV 192249. In terms of the number of basal tillers, lines ICFV 192449, Local check, ICFV192456, and ICFV 192239 showed the best tillering capacity. Lines that tillered least were ICFV 192415, ICFV 192444) ICFV192401, and ICFV 1922395.

Lines that performed best in the number of productive tillers produced were ICFV 192438, Local check, ICFV192456, and ICFV 192249. One line outperformed the local check in terms of the number of both basal tillers and productive tillers. Lines ICFV 192415, ICFV 192444, ICFV 192419, and ICFV 1922395 produced the least number of productive tillers. The greatest plant heights were recorded in ICFV 192396, ICFV 192422, ICFV192403, and ICFV 1922424 and the shortest lines were ICFV 192452, ICFV 192439, ICFV192451, and ICFV 192450.

Lines that matured earliest included ICFV 192426, ICFV 192398, ICFV192431, and ICFV 192315 and the late maturing ones were ICFV 192410, ICFV 192412, ICFV192434, and ICFV 192396. In terms of earliness, the local check was outperformed by a number of the experimental lines.

Lines that had more ears harvested per plant were ICFV 192449, Local check, ICFV192398, and ICFV 192454 and those that had the least number of ears harvested per plant were ICFV 19210, ICFV 192447, ICFV192435, and ICFV 192408.

Maximum 1000 seed weights were recorded in lines ICFV 192433, ICFV 192440, ICFV192425, and ICFV 192405 and those that had the least 1000 seed weights were

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ICFV 192454, Local check, ICFV192451, and ICFV 192441. The local check was among the lowest 1000 seed weight lines suggesting low yield qualities. The richest lines in terms of calcium concentration were Local check, ICFV 192455, ICFV 192420, and ICFV 192433. Those with lower calcium content were ICFV 192446, ICFV 192436, ICFV 192435, and ICFV 192402.

The number of ears harvested per plant and the number of days to 50% flowering showed Genotype + Genotype by Environment interaction ($P< 0.01$ and $P< 0, 05$ respectively). The agronomic and nutritional performance of finger millet at Kushinga Phikelela Agricultural College is shown in Table 4.

Table 4: Kushinga Phikelela Agricultural College finger millet agronomic and nutritional performance results

	No. of days to 50% flowering		**Plant height (cm)**		**No. of basal tillers per plant**		**No. of productive tillers /plant**		**No. of days to maturity**		**No. of ears harvested/plot**		**No. of ears harvested/plant**		**1000 seed weight (g)**		**Calcium concentration (ppm)**	
	Gen	days	Gen	(cm)	Gen.	Tillers	Gen.	Tillers	Gen.	Days	Gen.	Ears	Gen.	Ears	Gen.	(g)	Gen.	(ppm)
Minimum		66		43.1		3.13		2.625		119		22		2.75		1.82		3713
Maximum		86		84		14.4		9.625		140		172		21.5		2.82		7832
Mean		77.74		66.7		6.06		4.722		131.1		52.6		6.577		2.352		5003
	ICFV 192435	84^{a}	ICFV 192432	82^{a}	ICFV 192449	13.750^{a}	ICFV 192456	7.688^{a}	ICFV 192410	139.00^{a}	ICFV 192449	149.0^{a}	ICFV 192449	18.63^{a}	ICFV 192440	2.7500^{a}	ICFV 192455	7069^{a}
	ICFV 192447	83^{ab}	ICFV 192422	80.56^{a}	ICFV 192439	10.44^{ab}	ICFV 192439	7.25^{a}^{b}	ICFV 192408	139.00^{a}	Local Check	126.5^{ab}	Local Check	15.81^{ab}	ICFV 192420	2.7250^{ab}	Local Check	6983^{a}
	ICFV 192412	83^{ab}	ICFV 192430	79.813^{ab}	ICFV 192456	9.563^{abc}	ICFV 192449	7^{ab}	ICFV 192412	138.50^{a}	ICFV 192454	107.5^{abc}	ICFV 192454	13.44^{abc}	ICFV 192433	2.6900^{abc}	ICFV 192431	6594^{ab}
	ICFV 192408	82^{ab}	ICFV 192396	79.313^{ab}	ICFV 192426	8.50^{ab}^{cd}	ICFV 192438	7^{ab}	ICFV 192396	138.50^{a}	ICFV 192398	106.00^{abcd}	ICFV 192398	13.25^{abcd}	ICFV 192444	2.660^{abcd}	ICFV 192427	6575^{ab}
	ICFV 192424	82^{ab}	ICFV 192406	78.88^{a}^{bc}	ICFV 192438	8.375^{abcd}	Local Check	6.69^{a}^{b}	ICFV 192434	136.0^{ab}	ICFV 192429	94.5^{ab}^{cde}	ICFV 192429	11.81^{abcde}	ICFV 192415	2.6500^{abcd}	ICFV 192409	6500^{abc}
	ICFV 192434	78^{abcd}	ICFV 192434	68.188^{abcdefghijk}	ICFV 192433	5.69^{bc}^{d}	ICFV 192423	4.438^{ab}	ICFV 192435	131^{abc}	ICFV 192411	45.5^{cd}^{ef}	ICFV 192423	5.438^{cdef}	ICFV 192443	2.3950^{abcdefghi}	ICFV 192430	4798^{abcd}
	ICFV 192432	78^{abcd}	ICFV 192446	67.88^{a}^{bcdefghijk}	ICFV 192424	5.625^{bcd}	ICFV 192418	4.438^{ab}	ICFV 192424	131^{abc}	ICFV 192423	43.5^{cd}^{ef}	ICFV 192407	5.44^{cd}^{ef}	ICFV 192408	2.3900^{abcdefghi}	ICFV 192428	4784^{abcd}
	ICFV 192428	78^{abcd}	ICFV 192456	66.63^{a}^{bcdefghijkl}	ICFV 192405	5.563^{bcd}	ICFV 192422	4.375^{ab}	ICFV 192414	131^{abc}	ICFV 192407	43.5^{cd}^{ef}	ICFV 192402	5.375^{cdef}	ICFV 192414	2.390^{abcdefghi}	ICFV 192444	4768.5^{abcd}
	ICFV 192427	78^{abcd}	ICFV 192417	66.5^{abc}^{defghijkl}	ICFV 192437	5.500^{bcd}	ICFV 192421	4.375^{ab}	ICFV 192406	131^{abc}	ICFV 192402	43^{cdef}	ICFV 192397	5.313^{cdef}	ICFV 192419	2.370^{abcdefghi}	ICFV 192440	4763.6^{abcd}
	ICFV 192416	78^{abcd}	ICFV 192394	65.94^{a}^{bcdefghijkl}	ICFV 192400	5.50^{bc}^{d}	ICFV 192394	4.375^{ab}	ICFV 192400	131^{abc}	ICFV 192397	42.5^{cd}^{ef}	ICFV 192443	5.25^{cd}^{ef}	ICFV 192448	2.345^{abcdefghi}	ICFV 192414	4758^{abcd}
	ICFV 192450	71.5^{cd}	ICFV 192427	48.31^{k}^{l}	ICFV 192396	4.375^{cd}	ICFV 192427	3.250^{ab}	ICFV 192444	127.0^{abc}	ICFV 192405	31.50^{ef}	ICFV 192405	3.938^{ef}	ICFV 192438	2.0350^{fghi}	ICFV 192396	4171.4^{bcd}
	ICFV 192426	71^{cd}	ICFV 192454	47.63^{k}^{l}	ICFV 192447	4.313^{cd}	ICFV 192444	3.188^{ab}	ICFV 192397	124.50^{bc}	ICFV 192416	31.00^{ef}	ICFV 192416	3.875^{ef}	ICFV 192428	2.035^{fghi}	ICFV 192410	4157^{bcd}
	ICFV 192420	71^{cd}	ICFV 192452	46.44^{k}^{l}	ICFV 192425	3.938^{cd}	ICFV 192415	3.188^{ab}	ICFV 192450	123.0^{bc}	ICFV 192406	31.00^{ef}	ICFV 192406	3.875^{ef}	ICFV 192429	2.015^{ghi}	ICFV 192404	4115^{bcd}
	ICFV 192431	70.5^{cd}	ICFV 192451	45.75^{l}	ICFV 192415	3.750^{cd}	ICFV 192419	3.0625^{ab}	ICFV 192431	122.50^{bc}	ICFV 192425	29.50^{ef}	ICFV 192425	3.688^{ef}	ICFV 192453	1.9850^{hi}	ICFV 192402	4019.9^{cd}
	ICFV 192401	68.5^{d}	Local Check	45.63^{l}	ICFV 192401	3.500^{d}	ICFV 192401	2.875^{ab}	ICFV 192426	120.50^{c}	ICFV 192447	25.00^{f}	ICFV 192447	3.125^{f}	Local Check	1.9550^{i}	ICFV 192446	3911^{d}
LSD		4.945		10.802		2.8		2.212		5.657		34.25		3.933		0.262		1103

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CV%		3.2		7.2		23.1		23.4		2.2		29		29.9		5.6		11
S.e.d		2.474		5.375		1.4		1.107		2.831		17.04		1.968		0.131		552.1
Sig.		<.001***		<.001***		<.001***		0.002**		<.001**		<.001***		<.001***		<.001***		<.001**

Key: Means that do not share a letter are significantly different and the top five, middle five and bottom five means were computed. Gen = Genotype, **, ***= indicate significance at P<0.05 and P< 0.01 respectively.

The mean performance of finger millet at the Kushinga Phikelela Agricultural College site showed a significant difference (P< 0.001) in nine variables of 64 genotypes (Table 4). These included the number of days to 50% flowering, plant height, the number of basal tillers, the number of days to maturity, the number of ears harvested per plant, the number of ears per plot, 1000 seed weight and Ca concentration. The number of productive tillers also showed a significant difference (P<0.05) among the genotypes. The rest of the variables did not show any significant difference. The performance of the genotypes at Grasslands Research Station is shown in Table 5.

Table 5: Grasslands Research Station finger millet agronomic and nutritional performance results

	NO. OF DAYS TO 50% FLOWERING		PLANT HEIGHT (CM)		NO. OF DAYS TO MATURITY		CA CONCENTRATION (ppm)	
	Genotype	No of days	Genotype	Plant height (cm)	Genotype	Number of days to maturity	Genotype	Ca (ppm)
Minimum		72		30.3		118		3902
Maximum		97		75.1		146		8919
Mean		87.37		54.2		136.2		5587
	ICFV 192394	96.5^{a}	ICFV 192403	73.188^{a}	ICFV 192440	145.5^{a}	ICFV 192398	8067^{a}
	ICFV 192412	95.5^{ab}	ICFV 192396	73.06^{a}	ICFV 192412	145.5^{a}	Local Check	7502^{ab}
	ICFV 192404	94.5^{abc}	ICFV 192422	69.19^{a}	ICFV 192410	145.5^{a}	ICFV 192433	7267^{ab}
	ICFV 192452	94^{abc}	ICFV 192424	66.63^{ab}	ICFV 192434	145^{ab}	ICFV 192420	7223^{ab}
	ICFV 192447	94^{abc}	ICFV 192413	66.00^{ab}	ICFV 192413	145^{ab}	ICFV 192455	7073^{ab}
	ICFV 192427	90^{abcdef}	ICFV 192442	55.06^{ab}	ICFV 192439	137^{abcde}	ICFV 192407	5251^{ab}
	ICFV 192407	89^{abcdef}	ICFV 192435	55^{ab}	ICFV 192425	137^{abcde}	ICFV 192428	5212^{ab}
	ICFV 192448	88.5^{abcdef}	ICFV 192423	54.88^{ab}	ICFV 192416	137^{abcde}	ICFV 192440	5209^{ab}
	ICFV 192440	88.5^{abcdef}	ICFV 192448	54.6^{ab}	ICFV 192448	135.5^{abcde}	ICFV 192414	5120^{ab}
	ICFV 192400	88.5^{abcdef}	ICFV 192420	54^{ab}	ICFV 192422	135.5^{abcde}	ICFV 192443	5092^{ab}
	ICFV 192454	76.5^{cdef}	ICFV 192449	42.69^{ab}	ICFV 192415	126^{abcde}	ICFV 192425	4539.8^{ab}
	ICFV 192439	76.5^{cdef}	ICFV 192405	42.25^{ab}	ICFV 192431	124^{bcde}	ICFV 192447	4369^{ab}
	ICFV 192401	75.5^{def}	ICFV 192450	41.44^{ab}	ICFV 192454	123.5^{cde}	ICFV 192435	4226.8^{ab}
	ICFV 192420	75^{ef}	ICFV 192452	36.25^{ab}	ICFV 192426	122.5^{de}	ICFV 192436	4175^{ab}
	ICFV 192429	73.5^{f}	ICFV 192439	30.688^{b}	ICFV 192398	118.5^{e}	ICFV 192446	3995.3^{b}
LSD		8.459		16.7		9.207		1801
CV%		4.8		15.4		3.4		16.1
S.e.d		4.233		8.35		4.608		901.4
Sig.		<.001***		0.002**		<.001***		<.001***

Key: Means that do not share a letter are significantly different and only the top five, middle five and bottom five means were computed.

, * = significance at P<0.05 and P< 0.01 respectively.

The mean performance of finger millet at the Grasslands Research Station site showed a significant difference (P< 0.001) in three variables (Table 5). These are the number of days to 50% flowering, number of days to maturity, and Ca concentration. A significant difference (P<0.05) was also noted in plant height. The principal component analysis of the variables is in Table 6.

Table 6: Principal component analysis of finger millet performance

Variable	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8	PC9
Seedling vigour (1-5)	-0.255	-0.159	0.022	-0.054	0.051	0.189	-0.235	-0.502	0.025
Plant Count/plot	0.107	0.098	-0.075	-0.622	-0.163	0.525	-0.309	-0.112	-0.004
Days to 50% flowering	-0.244	0.173	-0.350	0.221	-0.165	0.179	0.070	0.101	0.090
Plant Height (cm)	0.174	0.413	-0.032	-0.041	0.128	-0.004	-0.079	-0.299	-0.305
Basal Tillers	0.288	-0.200	-0.147	0.177	-0.050	-0.067	0.053	-0.224	0.019
Productive tillers	0.290	-0.192	-0.112	0.117	0.012	-0.108	0.107	-0.291	-0.066
Lodging Sore(1-5)	0.009	-0.007	0.515	0.309	0.257	0.617	0.282	0.064	-0.249
Disease Pressure (0-9)	0.312	0.118	0.013	-0.046	-0.003	-0.111	0.038	0.333	-0.128
Pest Pressure score (0-9)	-0.110	0.129	0.265	0.417	-0.327	-0.131	-0.639	-0.020	-0.340
Days to maturity	-0.173	0.206	-0.414	0.212	-0.205	0.307	0.277	-0.004	-0.136
% Plant stand at harvesting	0.321	0.100	0.120	-0.160	-0.032	0.038	-0.008	0.138	-0.087
Number of ears harvested/ plot	0.255	-0.297	-0.084	0.224	-0.086	0.238	-0.187	0.031	0.252
Number of ears harvested /plant	0.255	-0.297	-0.084	0.224	-0.086	0.238	-0.187	0.031	0.252
Dry ear weight in t/ha	0.334	0.076	0.006	0.063	-0.037	0.060	-0.028	0.062	-0.008
Grain yield in t/ha	0.332	0.134	0.038	-0.029	-0.003	0.002	-0.014	0.068	-0.036
Biomass yield in t/ha	0.241	0.191	-0.300	0.159	0.163	-0.014	0.065	-0.388	-0.219
1000 Seed Weight (g)	0.006	0.396	0.233	0.134	0.361	-0.049	-0.063	-0.244	0.611
Calcium Concentration (ppm)	-0.088	-0.450	0.115	-0.151	0.162	-0.106	0.141	-0.208	-0.310
Iron concentration (ppm)	-0.075	-0.095	-0.376	0.051	0.713	0.065	-0.399	0.321	-0.163
Eigenvalue	8.0442	2.9820	1.4856	1.2302	0.9810	0.8206	0.8065	0.6057	0.5010
Proportion	0.423	0.157	0.078	0.065	0.052	0.043	0.042	0.032	0.026
Cumulative	0.423	0.580	0.659	0.723	0.775	0.818	0.861	0.892	0.919

The principal component analysis revealed that the first 9 components with an Eigenvalue of greater than 0.5010 contributed about 91.9% of the total variability in 64 genotypes (Table 6). The proportions of the total variance attributable to the first 9 principal components were 42.3%, 15.7%, 7.8%, 6.5%, 5.2%, 4.3%, 4.2%, 3.2% and 2.6% respectively. Dry ear weight in t/ha (33.4%) contributed more to the variation, followed by grain yield in t/ha (33.2%, per cent plant stand at harvesting (32.1%), disease pressure (31.2%), productive tillers (29%), basal tillers (28,8%), number of ears harvested per plant (25.5 %), number of ears per plot (25.5%), biomass yield in t/ha (24.1% and plant height (17.4%) in that order. These were the most important traits contributing to the overall variability. Important traits in the second principal component included plant height (41.3%), 1000 seed weight (39.6%), days to maturity (20.6%), biomass yield in t/ha (19.1%) and days to 50 % flowering (17.3%) in descending order. Below are the GGE biplots for two variables; the grain yield and calcium concentration from Figure 1. To Figure 4.

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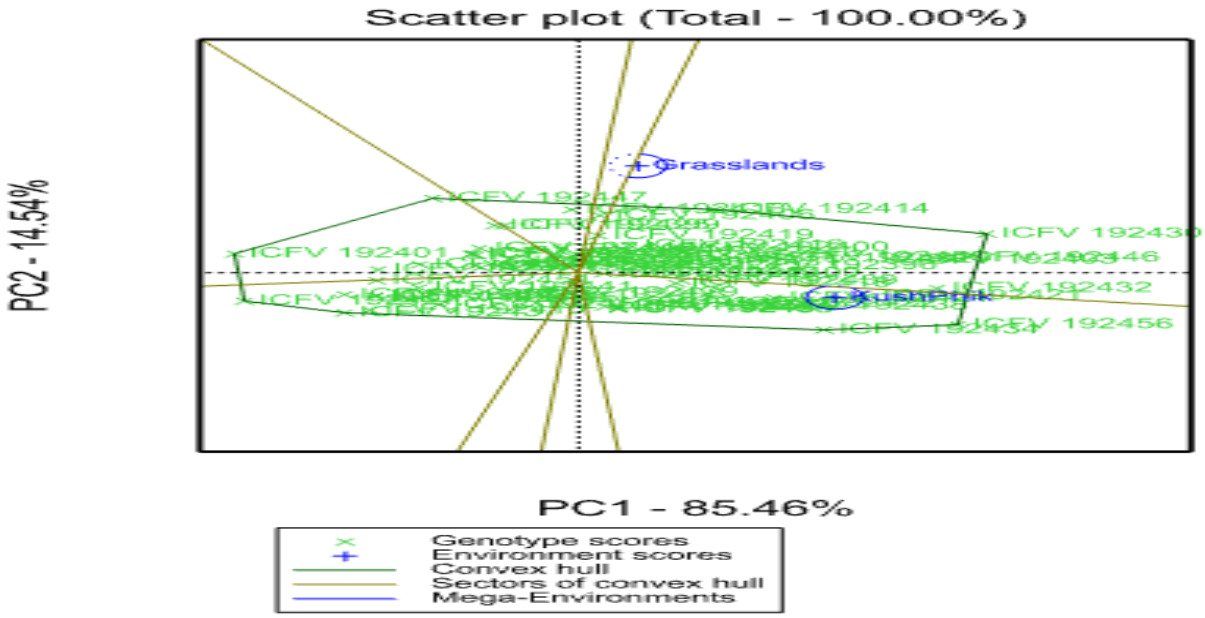

Fig. 1: Scatter plot showing the "Which-won-where" view of the GGE biplot for grain yield in t/ha.

In the “which won where” view of the scatter plot (Figure 1), the two environments are in different sectors and this means they constitute two mega environments. This outcome confirms the existence of the genotype by environment interaction for finger millet grain yield because the genotype ranking in terms of yield changed in the two environments. The genotype that performed best in terms of yield at Grasslands Research Station is ICFV 192430 (1.72t/ha). Genotypes that gave high yields at Kushinga Phikelela Agricultural College are ICFV 192456 (4.88t/ha), and ICFV 192434 (4.43 t/ha). All these genotypes are the winners since they are all located at the vertices in their respective environments.

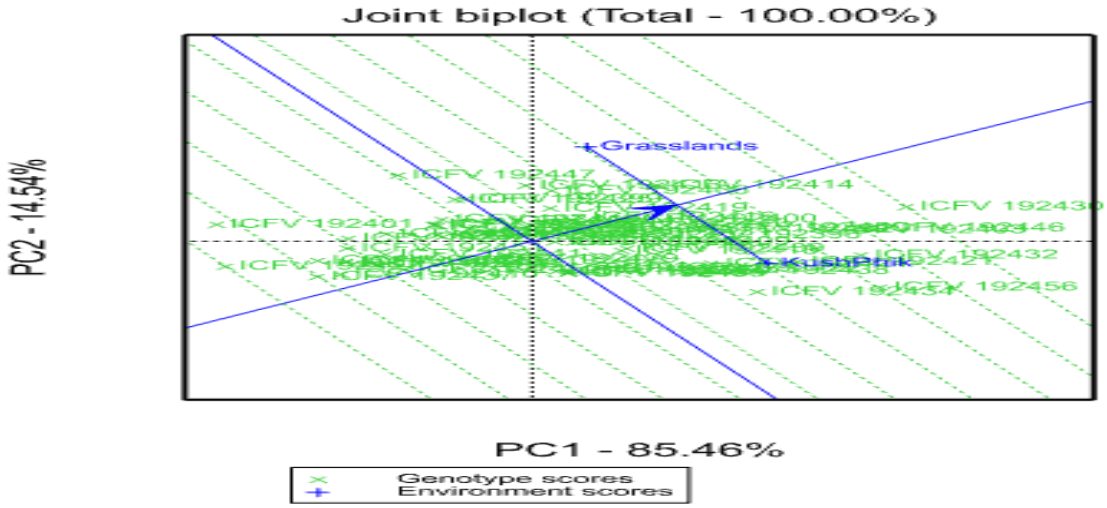

Fig. 2: Joint biplot showing genotype stability in terms of grain yield in t/ha

Figure 2 shows the genotypes that yielded best at Grassland which were ICFV 192430 (1.72t/ha), and ICFV 192414 (1.71t/ha). ICFV 192414 is closer to the biplot axis therefore it is stable, meaning its performance did not change in the two environments. On the other hand, ICFV 192447 is further away from the biplot axis meaning to say that it is an unstable genotype and its performance changes according to the environment. The genotypes that yielded best at Kushinga Phikelela Agricultural College were ICFV 192456 (4.88t/ha), followed by genotype ICFV 192430 (4.81t/ha) and ICFV 192432 (4.74t/ha), then 192446 (4.71t/ha) in that order. Genotype ICFV 192430 is more stable than ICFV 192456 because of its shorter distance from the biplot axis. The best performer in both environments was ICFV 192430, followed by ICFV 192446, ICFV 192456 and ICFV 192432 in that order. All these four top genotypes performed best at Kushinga Phikelela Agricultural College. ICFV 192414 was the best performer at Grasslands Research Station. The difference in performance between the two environments was greater for ICFV 192456 and ICFV 192432.

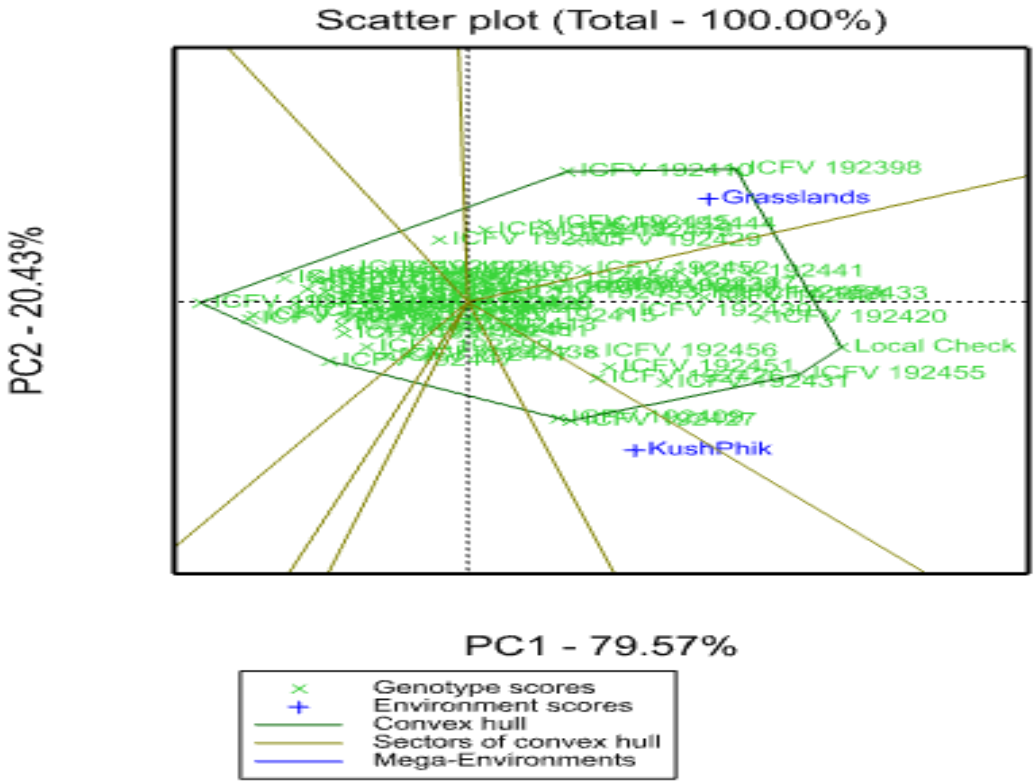

Fig. 3: Scatter plot showing the "Which-won-where" view of the GGE biplot for grain Ca content

In the 'Which-won-where' view scatter plot (Figure 3) for the Calcium concentration, the two environments are in different sectors and this means they constitute two mega environments. Genotypes that performed best in terms of grain Ca content at the Grasslands Research Station site are ICFV 192398 (8067.3 ppm), and ICFV 192440 (5209 ppm). Genotypes that gave high Ca content at Kushinga Phikelela Agricultural College include ICFV 192427 (6575 ppm) and ICFV 192409 (6409.55 ppm), with genotype ICFV 192409 as the winner in this environment. In terms of calcium concentration, there was also genotype by environment interaction since genotype ranking in both environments changed ranks concerning their performance.

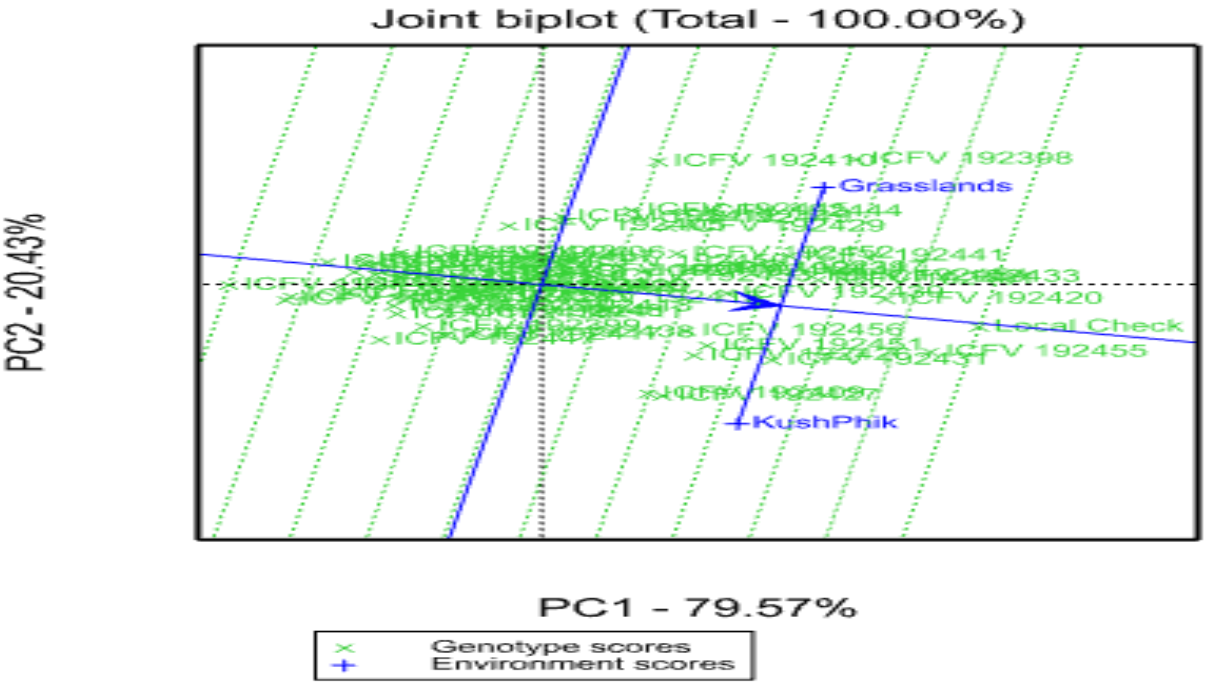

Fig. 4: Biplot showing genotype stability in terms of grain Ca content.

Figure 4 is a finger millet grain calcium content joint biplot. The local check genotype is very stable with high calcium content since it is very close to the Average Environment Axis. It is followed by ICFV 192455 and ICFV 192420 in terms of stability.

V. DISCUSSION AND CONCLUSION

A. Discussion

The results obtained from this research are from a crop that was established in the first week of January 2023. Kushinga Phikelela Agricultural College received 511.5 mm of rainfall (January to April) during the crop life cycle. During the same period, Grasslands Research Station received 568.3mm. The total rainfall received during the 2022/2023 agricultural season was 901mm and 968mm for the Kushinga Phikelela Agricultural College and Grasslands Research Station sites respectively.

- *Analysis of variance*

Similar results in variability (Table 3) in finger millet were recorded by earlier researchers, particularly in plant height, the number of days to 50% flowering, number of days to maturity, number of productive tillers, number of ears per plant, grain yield /ha and biomass yield per/ha (Anuradha & Patro, 2019; Umar & Kwon-Ndung, 2014).

The number of days to 50% flowering in the combined analysis results (Table 3) falls within the range of those found by earlier researchers. Aparna *et al*., (2020), reported finger millet genotypes that can take up to 103 days to 50% flowering. Lines that flower early are vital to farmers since they can fit well in the short rainfall seasons that are characteristic of the arid and semi-arid regions as these lines are likely to escape drought whereas late-flowering lines need long rain season since they will also mature late. Generally, lines at the Kushinga Phikelela Agricultural College site flowered earlier (68.5 to 84 days) than those planted at the Grasslands Research Station site (73.5 to 87. 37 days). These differences could be a result of environmental differences as the Kushinga Phikelela Agricultural College site has clay loam soil that has higher moisture and nutrient retention capacity than the sandy loam soils found at the Grasslands Research Station site. In addition, high soil Phosphorus levels and moisture stress can accelerate flowering and maturation (Wafula, Korir, *et al*., 2016). Differences in heat units between the two environments could have also contributed to the difference in flowering days.

Leku (2020), reported the number of tillers per plant among the evaluated genotypes to be up to 40. This contradicted the findings of this research since in the combined analysis (Table 3), the number of basal tillers ranged from 3 to 10.1 and productive tillers ranged from 2.5 to 5.96. This could have been caused by a drought period that affected both sites during the third and fourth week after crop emergence. The tiller number was found to be positively correlated to the final grain yield (Tilley *et al*., 2019). Therefore, this secondary trait can be used in the selection index by breeders to select high-yielding varieties.

Comparing the mean plant height with the reports from other researchers (Backiyalakshmi *et al*., 2021; Umar & Kwon-Ndung, 2014; Keba *et al*., 2022), these results reflect that the genotypes were shorter. Umar & Kwon-Ndung (2014), reported a plant height range of 43cm to 170cm which is wider than what our study found. The difference might be due to the genetic make-up of the lines as well as the environment. The advantage of short varieties is that they can carry the ear and resist lodging. Lines at the Kushinga Phikelela Agricultural College site were generally taller than those at the Grasslands Research Station site. This could be attributed to differences in soil texture and moisture retention capacities of the two sites' soils. There was a fast growth rate in clay loam soils at Kushinga Phikelela Agricultural soils which resulted in long internodes, hence tall plants.

The average number of days to maturity in our findings concurs with findings by some authors who reported a range of 105 to 146 days to maturity of finger millet (Hebbal *et al*., 2018). Lines at the Kushinga Phikelela Agricultural College site took shorter days to mature (120.5 to 139 days) than those at Grasslands Research Station (118.5 to 145.5 days). This difference could be due to microclimatic conditions like soil condition, moisture and temperature within the growing environment. Earliness in maturity is important in arid to semiarid regions for the success of the crop since rainfall seasons are now becoming shorter and shorter due to climate change. Also considering the areas where finger millet is being grown in Zimbabwe like regions 4 and 5, the rainy season is short hence earliness trait is very important.

The average number of ears harvested per plant at both sites, according to our study, was lower than that recorded by other authors. A range of 17- 26 ears per plant was reported by earlier researchers (Hebbal *et al*., 2018; Backiyalakshmi *et al*., 2021). The number of ears harvested per plant is an important component of yield. More ears per plant contribute to more yield.

The performance of the lines in terms of 1000 seed weight is within the range of what other authors recorded, but a maximum of up to 3,29 g per 1000 finger millet seed can be achieved according to Backiyalakshmi *et al*. (2021). Greater 1000 seed weight is desirable since it is a function of seed quality, milling percentage and yield (Deivasigamani & Swaminathan, 2018). It is important in seed germination, seedling vigour and growth as well as plant performance, as influenced by the size of the embryo and the quantity of stored nutrients (Deivasigamani & Swaminathan, 2018).

The average performance of the lines at both sites in terms of grain calcium concentration was by far above the average recorded by other authors (3440 ppm) (Devi *et al*., 2014). The lines at Kushinga Phikelela Agricultural College could have been outperformed by those at Grasslands Research Station in grain calcium content because of the difference in inherent soil fertility in the two sites.

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Keba *et al*. (2022), also reported the same results of genetic variability in plant height, grain yield and number of ears per plant. Umar & Kwon-Ndung, (2014) also reported significant finger millet genetic diversity in the number of basal tillers, plant height, days to flowering, number of productive tillers, grain yield, and 1000 seed weight. Genetic diversity in 1000 seed weight and plant height of bread wheat was also reported by Umar & Kwon-Ndung, (2014). This substantial genetic variation can be exploited for the improvement of finger millet (Anuradha & Patro, 2019).

- *Principal Component Analysis.*

The principal component analysis revealed that the first 9 components with an Eigenvalue of greater than 0.5010 contributed about 91.9% of the total variability.

Principal component analysis in this study confirmed that the first principal components contributed the maximum number of characters towards genetic diversity and these traits could be effectively used for further breeding programs to create more variability in finger millet improvement. Suman *et al*. (2019), reported the same results with variables like grain yield, the number of productive tillers per plant, the number of days to flowering and the number of days to maturity contributing to total variability. This implies that these traits should be prioritised in the finger millet improvement programme. Characters with high variability are expected to provide a high level of transgressive segregation in breeding populations. This is important for breeders to investigate high-yielding and nutrient-dense genotypes through conventional breeding. Several authors indicated that different morphological traits of different crops contribute to the overall variability of a species (Suman *et al*. 2019).

- *Genotype + genotype * Environment analysis*

In the "which won where" view of the scatter plot, the two environments are in different sectors and this means they constitute two mega environments. This outcome confirms the existence of the genotype-environment interaction for finger millet grain yield because the genotypes' ranking in terms of yield changed in the two environments. Figure 1 depicts that lines at the Kushinga Phikelela Agricultural College site performed better than those at the Grasslands Research Station site in terms of yield per ha. This is against the background that the Grasslands Research Station site received more rainfall (968mm) than the Kushinga Phikelela Agricultural College site (901mm) during the growing season. This high performance could be attributed to differences in soil texture and its associated properties. Kushinga Phikelela has clay loam soils which hold more water and nutrients. Nutrient leaching is less in these soils than in the sand loam soils found at Grasslands Research Station. The trial at Grasslands Research Station was also affected by quelea birds which affected yield.

Similar trends of observations in Figure 2 were recorded by earlier researchers (Khan *et al*., 2021). According to Kocaturk *et al*. (2019), a high-yielding and stable genotype across all environments is the best for general adaptability These stable and high-yielding genotypes can be incorporated into the breeding program for finger millet variety improvement (Khan *et al*., 2021).

Our findings on the finger millet grain calcium content of finger millet (Figure 3 and Figure 4) are not consistent with the results from other researchers (Hassan *et al*., 2021; Devi *et al*., 2014; Ramashia *et al*., 2019). The grain calcium content of most lines was higher than the average recorded (3440 ppm) in the literature. Some genotypes like ICFV 192398 (8067 ppm) and ICFV 192455 (7069 ppm) among others, had more than double the average amount of grain calcium content (3440 ppm) in finger millet as reported in the literature (Devi *et al*., 2014).

Generally, genotypes performed better in terms of grain yield at the Kushinga Phikelela Agricultural College site than at the Grasslands Research Station site. This could be because of differences in soil texture and soil moisture, agroecology, and temperature among other micro-environmental and plant growth parameters between the two sites. Conversely, in terms of grain calcium concentration, performance was better at the Grasslands Research Station. This could also be a result of differences in soil texture and the inherent soil nutrient composition of the two sites. Since the management of the trials was the same the two sites proved to have high discriminative powers for the genotypes in terms of grain yield and calcium concentration respectively.

B. Conclusion

This study revealed that the evaluated finger millet genotypes had greater levels of morphological and nutritional (Ca) variability and thus possible genetic diversity. The combined mean performance of finger millet showed a significant difference in eight out of sixteen variables of the 64 genotypes. These were the number of days to 50% flowering, plant height, number of basal tillers per plant, number of days to maturity, number of ears harvested per plant, 1000 seed weight and Ca concentration.

Plant count per plot, plant height, basal tillers, productive tillers, 1000-grain weight, productive tillers per plant, days to maturity, per cent plant stand at harvesting, number of ears harvested per plant, number of ears harvested per plot, dry ear weight, grain yield, and biomass yield were the most important traits that contributed to 91.9% of the total variability. These traits can be prioritised in the finger millet improvement programme. The GGE biplot model provided a superior representation of the Genotype by Environment Interaction (GEI), according to the current study. The two environments constituted two mega environments and different genotypes performed differently in terms of agronomic and nutritional performance in the two environments. At Grassland Research Station, ICFV 192430 and ICFV 192414 were the best yielders with 1.72t/ha and 1.71t/ha respectively.

Whereas, at Kushinga Phikelela Agricultural College were ICFV 192456 (4.88t/ha), followed by genotype ICFV 192430 (4.81t/ha) and ICFV 192432 (4.74t/ha), then ICFV192446 (4.71t/ha) in that order.

It was interesting to observe that, the top five in terms of high Ca concentration were dominated by the experimental genotypes at all sites where ICFV 192455 had the highest grain calcium content (7069 ppm) at Kushinga Phikelela Agricultural College surpassing the Local Check that recorded 6983 ppm then ICFV 192431 (6594 ppm), and ICFV 192427 (6575 ppm). The genotypes that performed better at the Grasslands Research Station site with regards to calcium grain content were (ICFV 192498 (8067 ppm), ICFV 192433 (7267 ppm), and 192420 (7323 ppm) among others.

C. Recommendation

Genotypes with good agronomic and nutritional performance should be promoted for further multi-locational trials and released for commercial production in Mashonaland East and other provinces of the country. Genotypes ICFV 192430, ICFV 192414, ICFV 192456, ICFV 192430, ICFV 192432, and ICFV 192446 can be evaluated for their grain yield performance. For calcium content, ICFV 192455, ICFV 192431, ICFV 192427, ICFV 192498, ICFV 192433, and ICFV 192420 should be evaluated. Promoting genotypes with both high yield potential and high calcium concentration is also recommended.

There is a need to dedicate genetic and financial resources towards research of finger millet varieties to ensure food and nutritional security. Farmers can also consider providing supplementary irrigation to attain the full potential of the crop and take finger millet production as a business. In addition, baseline soil analysis should be done before the trials are planted and post-harvest to correlate the final Ca grain concentration.

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