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FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE

Evaluation of genetic gains, grain yield potential, and agronomic performance of ultra-early maize hybrids under drought stress.

NIGEL HONDO

B213265B

A dissertation submitted in partial fulfilment of the requirements of the Bachelor of Agricultural Science Honors Degree in Crop Science

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Supervisor: Mr. K. Mutsengi

Co-supervisor: Mr. M. Mushayi

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ABSTRACT

Maize (Zea mays L.) is a crucial staple crop globally. Its production has been severely constrained by drought, which has been worsened by climate variability. Drought occurrence is expected to become more frequent; hence, the implementation of adaptive measures such as developing drought-tolerant maize hybrids is of paramount importance. In such a way, assessing genetic gains in the maize breeding programs will allow monitoring of breeding efficacy and genetic progress. The present study was conducted to evaluate the performance of newly developed ultra-early maturing maize hybrids for grain yield potential, agronomic performance, and genetic gains. Twenty-five genotypes consisting of 10 experimental hybrids and 15 commercial check hybrids were evaluated across six sites laid out in a 5 x 5 alpha lattice block, replicated three times per site. The results showed a significant variation in grain yield and most measured agronomic traits across sites ($p<0.05$). The hybrid named EXP5 had the highest yield, 2.14t/h. Positive realised genetic gains of selected genotypes over the population's mean, the best commercial check, and the mean of all checks were obtained for grain yield and most measured traits. The selected hybrids had a 28.8% gain on grain yield over the mean of the population, and 38.5% over the mean of all commercial checks. This showed a great improvement in grain yield performance in newly developed ultra-early maize hybrids.EXP5, EXP7, EXP2, and EXP9 were recommended for advancement to the next stage for further testing due to their high performance. The study's findings demonstrated the progress in breeding drought-tolerant varieties with desired agronomic traits in Seed Co's maize breeding programs. They also reflected the need for continuous investment in maize breeding programs to achieve higher realised genetic gains. Results from the study will add to the existing knowledge on ultra-early maize hybrids as an important step towards climate change adaptation.

Key words: Drought, Ultra-early maize hybrids, Genetic gains, Grain yield potential, and agronomic traits

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DEDICATION

This thesis is a special dedication to my Father, Nicolas Hondo.

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LIST OF ABBRIVIATIONS

SSA: Sub-Saharan Africa

GY: Grain yield

STR: Sterility

EH: Ear height

FAOSTAT: Food and Agriculture Organisation Statistics

NP: Number of plants.

GW: Grain weight

SD: Silking date

ASI: Anthesis to silking interval

AD: Anthesis date

CIMMYT:International Maize and Wheat Improvement Centre

LSD:Least significance difference

ANOVA:Analysis of variance

CV:Coefficient of variation

RG A:Realised genetic gain over mean of population

RG B:Realised genetic gain over mean of best check

RG C:Realised genetic gain over mean of all checks

CHAPTER 1

1.0 INTRODUCTION

1.1 Background of study

Maize (Zea mays L.) is a widely cultivated grain crop in Africa, covering about 42 million hectares (ha), which accounts for 21% of the total global maize production area (Epule *et al*.,2022). In terms of annual grain yield, the continent has a total share of approximately 97 million tons, which accounts for only 8% of the annual global yield (FAOStat, 2023). It is an essential staple food crop for over 1.2 billion people worldwide (García-Lara & Serna-Saldivar, 2019) and is the third most important cereal crop after wheat and rice maize (FAOStat, 2023). Global maize production area (for dry grain) amounts to 197 M ha with a yield output of over 1.3 billion metric tonnes, including substantial areas in sub-Saharan Africa (SSA), Asia, and Latin America (FAOStat, 2021).

It is an important crop in Africa, particularly in the SSA countries, where it is consumed as a staple food. Maize provides over 30% of total calorie consumption to people in Sub-Saharan Africa (Nuss *et al*., 2010). In Zimbabwe, the crop contributes over 50 % of total calorie intake to an estimated population of over 16.1 million (Baudron *et al*., 2024). The crop can be consumed in various forms such as sadza, beverages, snacks, green mealie roasted or boiled, and steamed products. In more than half of the countries in Sub-Saharan Africa, people consume over 450g of maize per day (Ekpa *et al*., 2019). In addition to being consumed directly, maize is an essential source of feed for the animal industry. The crop has high protein and carbohydrate content, which provides energy and growth to animals. Carbohydrates constitute over 70 % of maize grain, while protein content can range between 8 to 11% in maize grain (Adrienn *et al*., 2018). This makes the crop useful in animal rations. Also, maize is a source of industrial raw materials. It is used to manufacture alcoholic beverages, food sweeteners and oil (Ranum *et al*., 2014). Starch and oil, two of its derivatives, are crucial components in the food processing industry and the production of many other goods. All these uses have made maize a crop of choice and an integral component of the farming systems in SSA to ensure food security and economic development.

Global population continues to increase, and is predicted to double in the next 30 years (Prasanna *et al*., 2021). Food production for major crops, including maize, must therefore increase by 2.4% annually to match the rising population. The average global maize grain yield is 6t/ha, while in most SSA countries, particularly Zimbabwe is below 2 tonnes per hectare (Mushayi *et al*., 2022;

Mushayi *et al*., 2025). The average maize yields of rainfed areas between 2007-2016 ranged between 1.68t/ha to 1.99t/ha in most SSA countries (FAOStat, 2018). The large yield gap is attributed to a plethora of biotic (diseases and pests) and abiotic stress (drought, heat, low nitrogen, soil acidity), worsened by the impacts of climate change (Mushayi *et al*., 2025). Among the abiotic stresses, drought stress causes up to 100% yield loss when susceptible cultivars are grown(Potopová *et al*., 2016). There is a need for an urgent solution to meet the global demand for the maize crop.

In 2023 to 2024 growing season was affected by El Niño-induced drought, which lowered maize grain (Shaolong and Wei,2024). Drought stress can affect the plant's water relations, photosynthetic gas exchange capacities, cell turgor, source-sink relationships, and various metabolic events (Rodrigues *et al.,* 2021). In severe cases, drought can trigger the remobilisation of stem reserves, leading to excessive stem and root lodging in maize (Nadeem *et al.,*2019). When maize plants are subjected to drought stress, the expression of important agronomic traits is hindered, leading to low crop productivity. Agronomic traits such as plant height, ear height, the number of ears per plant, and grain yield are affected during drought stress (Umar *et al.,* 2015). Exposure of maize to drought stress can cause a delay in the silking stage, which causes low yield due to reduced pollination performance.

In most countries in SSA, the maize crop is cultivated in rainfed areas which receive mostly 300-500mm annually. Recent projections stated that by 2050 temperature will rise by 2% under the current emission scenario (Tesfaye *et al*.,2018). This will cause more yield losses due to drought occurrence. Developing ultra-early maize hybrids that are drought tolerant, high-yielding, and resistant to pests and diseases should be the overriding consideration in SSA countries. Ultra-early maize hybrids are bred to mature earlier than other maize hybrids, which makes them suitable for areas with short growing seasons (Badu-Apraku *et al*.,2017). They are highly stable and productive, with the ability to yield more under optimal conditions. There is a need to breed, evaluate, select and deploy drought-tolerant ultra-early maize hybrids as a cushion to climate change, which is projected to increase in intensity and frequency. The creation of ultra-early maize hybrids that possess drought tolerance and demonstrate adaptability across various environments would aid in maintaining optimal grain yield, hence ensuring food security in Zimbabwe.

Moreover, assessment of realised genetic gains over time is a valuable tool in achieving successful breeding outcomes. Genetic gain estimation in maize breeding progams provides an opportunity to monitor breeding efficiency and genetic progress (Eriksson *et al*., 2018). Assessment of genetic gains helps to identify gaps and steps toward improvement strategies for more effective breeding programs. Increasing genetic gains in maize breeding programs will facilitate higher yields for farmers. It would be ideal to asses the rate of genetic gain achieved in new ultra-early maize hybrids. Therefore, the current study aims to evaluate ultra-early maize hybrids for grain yield potential, agronomic traits and the assessment of genetic gains under drought stress conditions.

1.2 Problem statement

Reported yield losses in maize due to drought can be up to 100% in susceptible maize varieties (Potopová *et al.,* 2016). There is a need for continuous breeding efforts to breed and identify new drought-tolerant maize varieties. Developing drought-tolerant maize varieties has been the primary focus for the Seed Co Ltd maize breeding program. As such, there are newly developed drought-tolerant ultra-early maturing maize hybrids that have not been evaluated for their grain yield potential and agronomic performance under drought stress conditions. Lack of information on the value of these novel maize hybrids will limit their use; hence, the need to evaluate them.

1.3 Justification

Understanding the grain yield potential and agronomic performance of these newly developed ultra-early maturing maize hybrids under drought stress will open up new avenues for the farmers and maize breeders at Seed Co Ltd. Superior drought-tolerant maize hybrids will be identified and recommended for further evaluation towards commercialisation. This will improve maize productivity, which ensures household food security and economic gains for the farmers. Moreover, understanding the realised genetic gains will help to know the efficiency of various breeding methodologies. This will aid plant breeders in selecting effective methods that result in higher genetic gains, hence increasing the success of breeding programs.

1.4.0 Objectives

1.4.1 Main objective

To evaluate newly developed ultra-early maturing maize hybrids for agronomic performance, grain yield potential, and genetic gains under drought stress conditions.

1.4.2 Specific objectives

1. To determine the grain yield potential of ultra-early maturing maize hybrids under drought stress conditions.

2.To determine the agronomic performance of ultra- early maturing maize hybrids under drought stress conditions.

3. To assess the realised genetic gains in newly developed ultra-early maturing maize hybrids under drought stress conditions.

1.5 Hypothesis

1. There is a significant difference in the grain yield potential of ultra-early maturing maize hybrids under drought-stress conditions.

2.There is a significant difference in agronomic performance of ultra-early maturing maize hybrids under drought stress conditions.

3. There are significant realised genetic gains in newly developed ultra-early maize hybrids over checks hybrids under drought stress conditions.

CHAPTER 2

2.0 LITERATURE REVIEW

2.1 Importance of maize

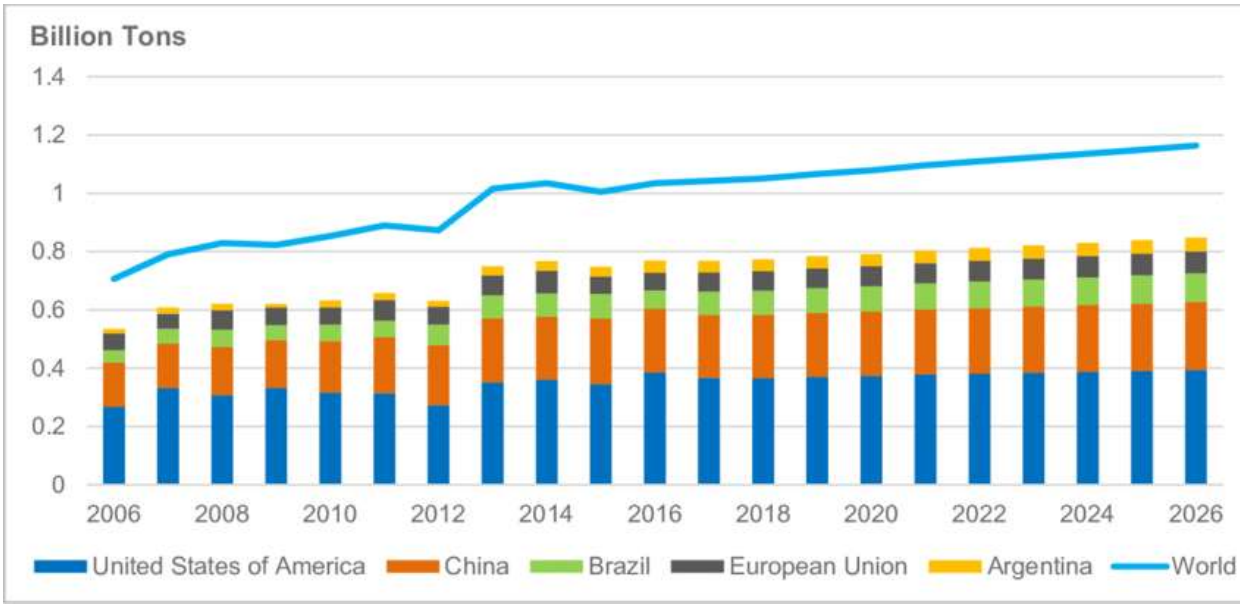
Maize (2n= *Zea mays* L.) is a crucial crop globally, and it plays a pivotal role in food security (Prasanna *et al*, 2016). The crop is the highest produced annually compared to other cereals (Farooq *et al.,* 2023). It is a staple crop for most of the countries in SSA, where it contributes to over 30% of the total calorie consumption (Ten and Hein, 2019). The crop is rich in nutrients, including carbohydrates, protein, fibre, vitamins, and minerals, which are vital for human health. Protein content in maize ranges between 7.7% to 12.07 %(Kaur *et al*., 2020). Carbohydrates present in maize kernels amount to 73% (FOStat, 2013) of the total nutrient constituents. This makes the crop important for food security for many people in SSA countries.

The consumption of animal-source foods has accelerated with economic development, hence the high demand for maize as feed, particularly in SSA (Erenstein *et al*.,2021). Maize plays a pivotal role in animal feeds due to its high protein content. The crop is used as a component in animal feed, where it is combined with other ingredients to create balanced diets for livestock. It is also used for silage, where the crop residues are preserved for pasture during the dry season. The characteristics of maize, such as high digestibility, high nutrient content, and high palatability, have a large impact on animal husbandry development (Guyader *et al*.,2018). Moreover, maize is a raw material for various industrial uses, which include the manufacture of cosmetics, alcoholic beverages, oil, starch, and pharmaceuticals. Maize starch has an essential role in pharmaceutical formulations due to its inherent properties. The starch acts as a binder in tablet formulations, ensuring the cohesion of tablet ingredients (Kunle &Olobayo, 2019). Maize also plays an integral role in the production of beverages. Most cereal beverages are produced by maize as a by-product (Louw & André, 2010), such as beer and mahewu in Zimbabwe.

Maize is also used in intercropping and crop rotations with legumes(Maitra &Banerjee,2020). Maize-legume intercropping enhances productivity, nutrient recycling, and resource utilisation, which ensures food security, especially for smallholder farmers (Nasar *et al.,* 2023). It also plays a crucial role in employment creation. The cultivation of maize employs the farmers and their families, which can improve the standards of living. Given its strategic importance, maize production has to improve in SSA. However, yield levels in Zimbabwe have remained stagnant at <1.5 t/ha owing to abiotic stresses, including drought.

2.2 Trends in maize production

The global maize production has increased in recent years. The growth can be attributed to improved crop cultivars, technological advancement and expansion in area under cultivation. The United States is the largest producer and consumer of maize, followed by China and Brazil, with an average of 90 million acres planted annually (FAOStat, 2021). South Africa is the largest maize producer in Africa (Ala-Kokko *et al*., 2021). In Africa, maize production amounts to 40.7 million hectares and accounts for 40% of cereal production, yielding 91 million metric tonnes annually (FAOStat, 2020). There is a significant difference in global maize production between Africa and other continents, owing to factors such as climate change-induced drought.



Source :(FAOStat,2024)

Figure 1.Growth in maize production over the past years

In Zimbabwe, maize production over the past five years has been highly variable due to rainfall patterns. In the 2019/2020 season, maize production was relatively low compared to the previous season. However, in the 2020/2021 season, there was a remarkable increase in yield, reaching an estimated 2.7 million metric tons. The season 2023/2024 has been severely affected by the El

Niño-induced drought, which lowered grain yield. Drought occurred on all critical growth stages, leading to low yields. The variation in maize production is mainly attributed to the frequency of drought, which has intensified amid climate change events. This has accelerated the need for ultra-early maturing maize hybrids that are drought tolerant.

2.3 Constraints to maize production

2.3.0 Biotic factors

The prevalence of abiotic factors affecting maize production has been affected by climate change. Maize production has been severely affected by biotic factors such as pests, diseases, and weeds. For instance, fall armyworm is the major pest affecting maize production in SSA, accounting for 11–58% of yield losses annually (Koffi *et al*., 2020). Diseases such as maize streak virus, grey leaf spot, northern corn leaf blight, common rust, and maize lethal necrosis are some of the important diseases affecting maize production across Africa. MSV is a threat to food security in SSA countries. In Zimbabwe, the disease is most prevalent in the high and middle velds, where the farmers grow the winter cereal rotations. The disease can cause yield losses of up to 100%, depending on the cultivar and the time of infection (Karavina, 2014). Weeds also affect maize production. They compete with crops for sunlight, nutrients, and space and produce chemicals such as phenolics, which inhibit plant growth. Yield losses of up to 100% can occur due to striga infestations in maize fields (Menkir and Abebe, 2020).

2.3.1 Abiotic factors

Abiotic factors such as drought stress, heat stress, soil salinity, and low nitrogen are the leading factors affecting maize production. Climate change has increased the impact of these factors on maize production.

2.3.1.0 Temperature

All crops have an optimal temperature range for growth; beyond that temperature, growth and development processes are hindered. The gradual increase in temperature, which causes drought stress, is among the major abiotic factors threatening maize production (Sallam *et al.*, 2018). Critical growth stages in maize, such as germination, grain filling, and flowering, are more sensitive to extreme temperatures. During germination, high temperature stress can greatly reduce seed vigour, and in extreme cases, may result in a complete loss of viability (Khaeim *et al*., 2022). The process of photosynthesis in maize plants is greatly disturbed by heat stress, which therefore limits the production of glucose for growth. This will result in low crop yield. Maize is a C4 plant, and it doesn't perform well in areas with very low temperatures. It thrives well in warmer environments where optimal temperatures are around 25 °C to 33 °C during the day(Sánchez *et al.,*2014). Prolonged exposure of maize to very low temperatures can cause cell damage and impede the process of photosynthesis, leading to poor yield.

2.3.1.1 Heat stress

Processes involved in photosynthesis, such as photophosphorylation, the Calvin cycle, electron transport, photochemical reactions, and thylakoid membrane fluidity, are sensitive to heat stress (Lakshmi *et al*., 2022). Therefore, the negative effect of heat stress on plants is caused by the rapid and excessive generation of reactive oxygen species (ROS). This impairs the photosynthetic process by reducing the rate of electron transport, deactivating photosystem II (PSII) and photosystem I (PSI), breaking down proteins and pigments, and ultimately leading to a decrease in crop production (Iqbal *et al.,* 2023). Yield losses in maize due to heat stress vary with growth stages; 15–46 yield losses were reported in maize fields at the flowering stage (Neiff *et al.*, 2019).

2.3.1.2 Drought stress

Drought has been a long-standing threat to maize production globally, especially amid climate variability(Basu *et al*., 2016). This is evidenced by recent El Niño-induced droughts in SSA countries. Drought stress reduces the availability of moisture to plants, absorption of water, and nutrients into the roots, leading to disruptions in the structural and biochemical processes of crops at the cellular and whole-plant levels (Rodrigues *et al.*, 2019). This results in a reduction of plant and leaf size, impacting the leaf area available for photosynthesis. The expression of secondary traits in maize is hindered, causing low crop productivity. These traits indirectly contribute to yield, and a negative effect on them will have a knock-down effect on yield. Prolonged drought stress can cause a delay in the silking stage, leading to poor synchronisation between the silk emergence and pollen shed. The days to mid-pollen, mid-silking and anthesis to silking interval increase by 5%,6%, and 33% respectively (Li *et al*.,2015). The vegetative, flowering and grainfilling stages are most sensitive to drought stress with reported yield losses of up to 50% (Sah *et al*., 2020). In severe cases, yield losses due to drought can reach up to 100% (Potopová *et al*., 2016).

2.4 Drought-tolerant traits in maize

Selecting for grain yield is difficult because it is a complex, polygenic trait; hence, breeders use grain-related traits in their selection programs(Blum, 2011).Drought-tolerant traits are encompassed when breeding for drought tolerance because drought stress can occur at an crop development stage. Secondary traits can improve precision in identifying genotypes that are drought-tolerant rather than focusing on grain yield alone (Ziyomo & Bernardo, 2013). The traits related to flowering, root architecture, earliness, prolificacy, stomatal conductance, and staying green are some of the important traits when selecting for drought stress tolerance in maize (Kosova *et al.*, 2014).

2.4.1 Earliness

The flowering time of maize is an important trait in breeding for drought tolerance. Developing cultivars that can escape drought by maturing early has been the primary focus in various maize breeding programs. Mid-season drought can be escaped by growing early maturing varieties (Badu-Apraku *et al.*,2014). Flowering time is correlated with yield under drought. The earliness matches the phenology of the crop with the rainfall patterns. Developing early-maturing varieties is an important tool for escaping terminal drought by completing the lifecycle before the onset of drought stress(Grewer *et al.*,2024).

2.4.2 Athesis to Silking Interval

It is the difference between the anthesis date and the silking date in maize. The anthesis to silking interval is a crucial trait related to drought tolerance. In general, male and female flowering in maize usually synchronise within 2–3 days, while under drought stress, it may be delayed, leading to reproductive failure(Li *et al*., 2015). Therefore, negative ASI is the rewarding trait when selecting for drought tolerance (Araus *et al.*, 2012). The shorter ASI indicates a drought-tolerant trait because pollen and silk emergence are well synchronised, hence efficient grain filling occurs, reducing yield losses due to drought. The anthesis-silking interval is well correlated to grain yield under drought stress(Ngugi *et al.*,2013).

2.4.3 Prolificacy and leaf rolling

Ears per plant (prolificacy), tassel size, and leaf rolling are also crucial traits when breeding for drought tolerance in maize.Ear prolificacy refers to the ability of plant to produce viable cobs.It is an essential drought tolerant trait which is positively correlated to grain yield. Ears per plant are some of the quantitative traits associated with drought tolerance in maize (Abdoul-Raouf Sayadi *et al*., 2016). The number of ears influences the yield in maize; hence, high EPP during drought stress indicates a drought-tolerant trait in the maize plant. Moreover, leaf rolling is an adaptive response of plants to drought stress conditions. One of the leaf movements under drought stress is the hydrostatic mechanism, which reduces light interception, leaf hydration, and transpiration. This will lead to low yields because the process of photosynthesis is affected, which produces food for plant growth. Therefore, delayed leaf rolling indicates the plant's ability to sustain itself under drought stress conditions (Effendi *et al.,* 2019).

In addition ,Leaf senescence has also been identified as an important drought-tolerant trait. In maize, the stay green trait is an indicator of drought adaptation (Samuel *et al.,* 2016). Therefore, delayed leaf senescence in maize is rewarding when breeding for drought tolerance.

2.5 Agronomic traits in maize

The agronomic traits in plants consist of plant structure, physiological traits and maturation traits that influence the performance of plants (Simmons *et al.,* 2021). Plant height, lodging resistance, high shelling percentage ,earliness, prolificacy/fertility, ear height, resistance to biotic and abiotic factors and grain yield are some of the important traits targeted by plant breeders in tropical regions (Rahman *et al.,*2015). Grain yield is the most critical agronomic trait, which contributes to food security and economic gain for farmers. It is influenced by kernel weight, kernel row, ear length, ear weight, ear diameter, ear height, days to silking and maturity (Abadassi *et al.,*2015). This principal trait is governed by many factors. Farmers desire maize genotypes with good standability, which can resist both stalk lodging and root lodging. Excessive plant height leads to lodging, reducing final yield, while optimal plant height promotes efficient light interception and biomass production, contributing to yield. The frequency of drought occurrence has raised the need for early maturing varieties in maize. The use of early maturing can help to reduce the effects of drought (Badu-Apraku *et al.,*2013), and it allows two harvests per season in regions which receive normal rainfall. In addition, genotypes which carry resistant traits to biotic and abiotic factors are mostly needed by farmers, especially in the face of climate change(Lybbert and Sumner., 2012).

2.7 Heterosis and genetic gains in maize.

Heterosis refers to the superiority of f1 progeny over its parents in terms of productivity, growth, development, and tolerance to various stresses (Begna *et al.,* 2021). It is estimated in three ways:

mid-parent heterosis, high-parent heterosis, and economic/commercial heterosis. A rationale for hybrid breeding is the systematic exploitation of heterosis (Schulthess *et al*., 2017). Commercial heterosis is the target for any breeding program since any new hybrid developed must surpass the performance of the existing varieties within its category. Economic heterosis brings about high yields and high tolerance to biotic and abiotic factors that affect crop production. Developing cross-combinations from different heterotic groups in maize helps to exploit heterosis. Heterotic groups provides an essential source of information that can be used to exploit heterosis (Laude *et al*., 2015). Economic heterosis can result in higher genetic gains, hence this can increase the economic prospects of farmers. The CIMMT has collaborated with the public and private sectors in the developing and deploying of multiple stress-tolerant varieties (Cairns and Prasanna, 2018; Prasanna et al., 2021). Recent research conducted under drought stress showed that newly developed drought-tolerant maize hybrids have a 25% yield advantage over available commercial cultivars (Setimela *et al*., 2017). In addition, these hybrids also maintain their performance in the normal rain season (Prasanna *et al*., 2021). This implies that genetic gains have been achieved in maize under drought stress.

2.8 Progress in breeding drought-tolerant maize hybrids

There have been many efforts to mitigate the impacts of drought on maize production. Breeding for drought tolerance in maize has been the major focus of international research institutions such as the International Maize and Wheat Improvement Centre (CIMMYT), the International Institute of Tropical Agriculture (IITA), and private sectors such as Seed Co. Ltd., Mukushi Seeds, and Klein Karoo Seed (K2) in Zimbabwe. For instance, CIMMYT commercialised DT hybrids such as CIM22EAPP1-02-09 in Eastern Africa (www.cimmyt.org). Private organisations such as Seed Co Ltd have developed and marketed DT maize hybrids, which include SC 301 and SC 303 under the 300 series and SC 419 and SC 437 under the 400 series (www.seedcoonlineshop.com). Pannar, a private seed organisation also in Zimbabwe, developed DT maize varieties such as PAN 3p-924pw, PAN 3A-124, and PAN 3r-524r (www.pannar.com). Lastly, ZAP43 is a DT maize hybrid developed and being marketed by Agri Seeds (www.pannar.com). Considering the above success in breeding for drought tolerance, there is still a need for developing more ultra-early maize hybrids with desired agronomic traits to ensure food security in the face of climate

CHAPTER 3

3.0 MATERIALS AND METHODS

3.1 Trial sites.

The 25 maize hybrids were evaluated in six locations, namely Rattray Arnold Research Station (RARS), Great Zimbabwe University, Africa University, Bindura University of Science Education, Save Valley and Chiredzi (CHRDZ). The descriptions of the six locations are summarised in Table 3.1.

3.1 Agroecological characteristics of testing sites

2
2
2
2
2

Notes:RARS=Rattray Anord Reseach Station ,GZ=Great Zimbawe University,AU=Africa University,BUSE= Bindura University of Science Education,SAVE =Save Valley ,and CHDZ=Chiredzi

3.2 Experimental design

The trials were laid out in a 5 x 5 alpha lattice design with three replications at each site. The 10 newly developed ultra-early maize hybrids were evaluated against 15 checks. Slope was used as a blocking factor in all testing sites. Each replicate had 5 incomplete blocks. The genotypes were planted in a two-row plot with 12 planting stations per row, yielding 24 planting stations per plot. The plot length was 6 m and the width was 90 cm, giving an area of 5.4 m^2 /plot. The distance between one plot to another was 50 cm, allowing for proper identification of plots and less competition between genotypes.

Yijk = μ+ Gj + Ei + GjEi + Ei (rk)(b) + eijk

Where: Yijk = observed response, μ= grand mean, Gj = the effect of the genotype, GjEi = genotype x environment interaction, Ei = effect of the environment, Ei(rk)(b) = error associated with the kth replication in blocks in ith environment, eijk= random error.

3.3 Agronomic procedures

All the crop management procedures were done according to CMMYT standards(CIMMYT,1999)

3.4 Germplasm used in the study

A total of 10 newly developed ultra-early maturing maize varieties sourced from Seed Co Ltd were used in this study. They were evaluated against 15 commercial checks. For the purpose of this study and confidentiality, all the varieties were coded as in Table 3.4.

3.4 Germpasm used in the study

Hybrid name	Attribute	Hybrid name	Attribute
23C-01	Experimental hybrid	23C-16	Check hybrid
23C-02	Experimental hybrid	23C-17	Check hybrid
23C -03	Experimental hybrid	23C-18	Check hybrid
23C-04	Experimental hybrid	23C-19	Check hybrid
23C-05	Experimental hybrid	23C-20	Check hybrid
23C-06	Experimental hybrid	23C-21	Check hybrid
23C-07	Experimental hybrid	23C-22	Check hybrid
23C-08	Experimental hybrid	23C-23	Check hybrid
23C-09	Experimental hybrid	23C-24	Check hybrid
23C -10	Experimental hybrid	23C-25	Check hybrid
23C-11	Check hybrid		
23C-12	Check hybrid		
23c-13	Check hybrid		

23C-14	Check hybrid
23C-15	Check hybrid

3.5 General crop management.

3.5.0 Land preparation and planting

The land preparation started in August 2024 .All the testing environments were phoughed using a tractor-drawn disc plough. A light discing operation was carried out in November 2024 to ensure a fine tilth for optimum germination and emergence. The plot area consisted of two rows with inter-row and intra-row spacing of 0.75m and 0.25m, respectively. Two seeds were sown per each planting station, and then thinned to one plant per station one week after crop emergence to achieve a plant population of approximately 53,333 per hectare.

3.5.1 Fertiliser and Water Management

A compound fertiliser(Compound D) containing nitrogen, phosphorus, and potassium in the ratio of 7:14:7, respectively, was applied as a basal application at a rate of 426kg per hectare at all the testing sites. Ammonium nitrate with a nitrogen content of 34.5% was split and applied as a top dressing fertiliser at a rate of 426kg per hectare at each site. The first half of the ammonium nitrate was applied four weeks after planting at a rate of 213kg per hectare, while the remaining half was applied six weeks after planting. The trials were rain-fed; however, supplementary irrigation was done at germination and seedlings' emergence to establish a good plant stand.

3.5.2 Weed and Pest Control

Weeds were controlled using mechanical and chemical control measures in all trials. The majority of weeds were destroyed during land preparation. Pre-emergence herbicide sprays of glyphosate were applied at a rate of 3.5L/ha. Stellar star was used as a post-emergence herbicide at a rate of 1 L/ha to control weeds such as shanva grass,yellow nutsedge and broadleaf weeds.Scouting of pests such as maize stalk borer (*Busseola fusca Fuller*) and fall armyworm (*Spodoptera frugiperda*) was done two weeks after planting. Dipterex granules were applied at a rate of 2kg /ha in the funnel of each plant to control the maize stalk borer. Emamectin was applied weekly in the crop funnel at a rate of 1 gram per litre to control fall armyworm (*Spodoptera frugiperda*).

3.6 Data collection

Data for grain yield and agronomic traits were collected before and after harvesting using the following criteria.

4.6 Agronomic traits recorded in the study

Trait	Abbreviation	Criteria used
Days to mid-pollen	DMP	Measured as the number of days from the effective planting date at 50% pollen shade.

Days to mid-silking	DMS	Measured as the number of days from planting to 50% silking.
Anthesis-silking interval	ASI	Calculated as the difference between DMP and DMS.
Plant height	PH	Determined by randomly selecting 10 plants from a plot and measuring the distance between the base of the plant and where the tassel started to branch.
Ear height	EH	Determined on those plants whose heights were measured by measuring the distance in centimetres from the plant base to the node that bears the upper ear.
Total stalk lodging	TL	Determined by adding the number of plants that lodged as a result of root and stalk lodging.
Number of ears	EHP	Determined by recording the number of ears harvested per plot.
Fertility	FLT	Determined by the number of cobs harvested per plant.
Field weight	FW	Determined by measuring the weights of ears in kilograms.
Grain weight	GW	Determined by weighing shelled grain from the net plot.
Moisture content	MC	Determined by recording the moisture percentage of grain after shelling.
Grain yield	GY	Expressed in t/ha was obtained from grain weight per net plot (2 rows) adjusted to 12.5% grain moisture. The formula used to calculate the grain yield is expressed below the table.
Ear diameter	ED	Determined on those selected ears whose length was measured by measuring the average ear diameter.

SOURCE: (CIMMYT, 1999)

Note: GY = $\left(\frac{GW}{NP}\right) * 10\ (100 - \frac{MO}{87.5})$

Where:

GY =Grain yield (kg/ha)

GW = Grain weight at harvest

MO=Moisture content (%) of grains at harvest

87.5 = Standard dry matter of grain at 12.5% as required by the maize grain marketing board in Zimbabwe.

NP = Net plot area (number of rows x intra row spacing x number of stations x inter-row spacing).

3.7 Data analysis

3.7.0 Analysis of variance (ANOVA)

Data analysis was performed using Genstat 18^{th} edition on the across-site average s analysis of variance. Fischer's unprotected LSD at a $p \leq 0.05$ significance level was used to separate hybrid and site means.

3.8.1 Realised genetic gains

Realised genetic gains achieved were measured focusing on the mean of selected hybrids against the mean population, the mean of the best check, and the mean of all checks in this study. Realised genetic gains were assessed for all the traits according to the procedures by Singh and Chaudhary(2004). The following formulas were used :

Realised gain (RG A): Realised genetic gains against the population mean (trial mean).

$$RG\ A=(MS-MP)/MP)*100$$

Realised gain (RG B): Realised genetic gains relative to the mean of the best commercial control hybrid.

$$RG\ B=(MS-MBC)/MBC)*100$$

Realised gain (RG C): Realised genetic gains relative to the mean of all commercial control hybrids

$$RG\ C=(MS-MC)/MC)*100$$

Where MS= mean of selected hybrids, MP= population mean, MBC= mean of best commercial .hybrid, and MC= mean of commercial hybrids

CHAPTER 4

RESULTS

4.1 Effects of Genotype x Environment interaction on grain yield across sites

The across-site analysis of variance indicated that the ultra-early maize genotypes differed in grain yield performance ($P<0.05$). The variation necessitates the need to identify the specific performance of ultra-early maize hybrids at certain sites. The GGE-biplot was used to asses the performance of hybrids in different environments.

4.2 Which-won-where

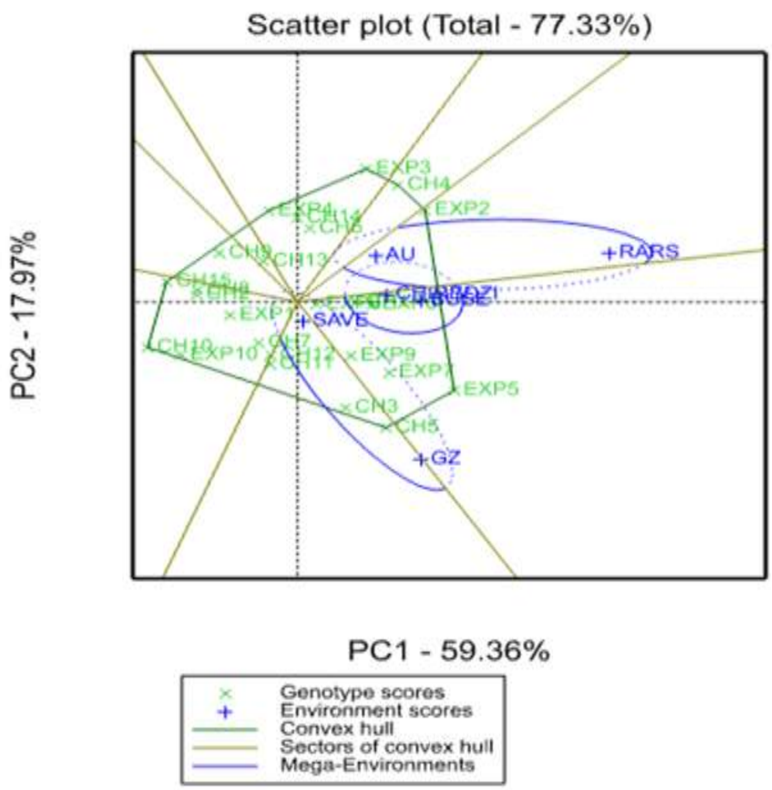


Figure 4.2 GGE Biplot polygons to determine which-won-where and the identification of 25 genotypes evaluated in six sites.

The crucial component of the biplot analysis is that it shows the highest and the lowest hybrids in a specific environment. The GGE-biplot grouped the environments into 3 mega-environments with AU and RARS being one environment, SAVE and GZ being one environment, and Chiredzi and Buse being one environment. The which-won-graph identified the best hybrids in different mega-environments. GGE biplot ranked CH3, CH5, EXP9, EXP7, CH11, CH12 and CH7 as the best performing hybrids in terms of grain yield in the Save and GZ mega environment. The EXP 6 and EXP 8 performed best in the BUSE and Chiredzi mega environment. The EXP 2 was the best-performing hybrid in the AU and RARS mega environment. The EXP 5 was the best performing in GZ.AU is ideal for CH13 and CH6. Hybrids such as EXP3, CH14, CH10, EXP10, CH9, CH4 had no specific adaptation certain environment.

4.3 Effects of Genotype x Environment interaction on Plant height across sites

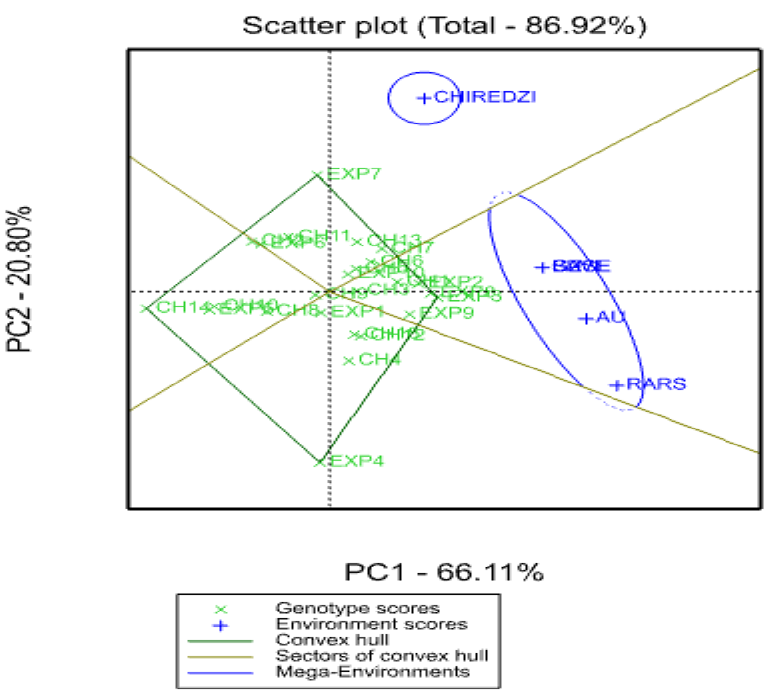


Figure 4.3 GGE Biplot polygons to determine which-won-where and the identification of 25 genotypes evaluated in six sites.

The genotype x environment interaction had an effect on plant height($p<0.05$).BUSE, RARS and AU were ranked as the same mega environment.CHIREDZI was the only site which was not in a mega environment. However, there was no specific performance of plant height in certain environments. This implies that there was an average performance of genotypes on plant height across all environments

4.4 Effects of Genotype x Environment interaction on EHP across sites

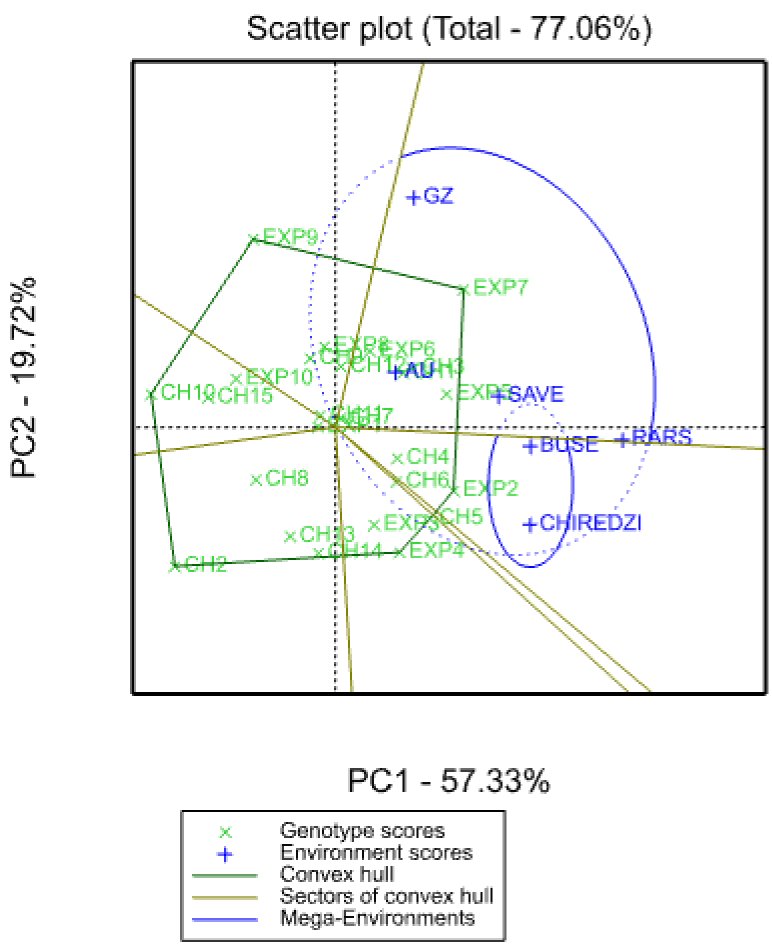


Figure 4.4 GGE Biplot polygons to determine which won where and the identification of 25 genotypes evaluated in six sites.

The genotype x environment interaction had an effect on the ear height of the plant ($p<0.05$). The GGE-bplot grouped GZ, SAVE, AU, CHIREDZI and RARS as one mega environment, and BUSE and CHIREDZI as one mega environment. CH4, CH6, CH5, EXP7, CH1, EXP6, CH3, and CH12 hybrids have the highest EHP in the GZ TO RARS mega environment.EXP 2 had the highest EHP in the BUSE and CHIREDZI mega environment.CH2 ,CH8 ,CH13,EXP9,CH10,CH15,EXP10 and CH14 hybrids had no specific adaptation.

4.5 Effect of genotypes on anthesis date across sites

1.5 Effects of genotype on Athesis date across sites

GENOTYPE	ENTRY	Rank	AD
EXP9	20	5	64.22^{a}
EXP8	19	13	63.22^{ab}
EXP3	14	9	63.11^{ab}
CH6	6	11	62.56^{ab}
CH4	4	6	62.44^{abc}
EXP6	17	7	62.11^{bc}
CH13	23	15	61.89^{bc}
CH7	7	14	61.78^{b}
CH3	3	8	60.67^{cd}
EXP2	13	4	60.11^{d}
EXP5	16	1	59.67^{d}
EXP7	18	3	59.33^{d}
CH14	24	12	59^{d}
CH5	5	2	58.44^{d}
CH1	1	10	58.11^{d}
Means			61.11

P-VALUE	<.001
SED	0.92
LSD	1.82

There was no interaction between environment and genotype on anthesis date (p>0.05). Genotype had an effect on AD(p<0.05). The EXP 9 had the longest days to mid-pollen shade, while CH1 had the shortest days to reach mid-pollen shade.

4.6 Effects of genotype on prolificacy/fertility across sites

4.6 Effects of genotype on prolificacy/fertility across sites

Genotype	Entry	Rank	Fertility
CH1	1	10	0.89
CH3	3	8	0.87
EXP7	18	3	0.86
EXP6	17	7	0.86
CH5	5	2	0.84
EXP2	13	4	0.81
CH14	24	12	0.80
EXP5	16	1	0.78
EXP3	14	9	0.77
CH4	4	6	0.76
EXP9	20	5	0.72
CH7	7	14	0.68
CH6	6	11	0.65
CH13	23	15	0.64
EXP8	19	13	0.63
Means			0.77
P-VALUE			0.127

SED	0.10
LSD	0.20
CV%	33.29

There was no significant interaction between environment and genotype on prolificacy (p>0.05). Genotype had no effect on prolificacy/fertility(p>0.05).CH 1 had the highest fertility rate, and EXP 8 had the shortest fertility rate.

4.7 Effects of genotype on ASI across sites

4.7 Effects of genotype on ASI across sites

Genotype	Entry	Rank	ASI
CH13	23	15	2.65
CH5	5	2	2.40
CH14	24	12	2.21
CH3	3	8	2.14
EXP7	18	3	2.04
EXP6	17	7	1.91
EXP5	16	1	1.76
CH7	7	14	1.56
EXP3	14	9	1.01
EXP9	20	5	1.00
EXP8	19	13	0.65
CH6	6	11	0.50
CH4	4	6	0.26
CH1	1	10	0.12
EXP2	13	4	-0.11
Means			1.34
P-VALUE			0.264

SED	0.86
LSD	1.70
CV%	101.81

There was no significant interaction between environment and genotype (p>0.05) on ASI. Genotype had no effect on ASI (p>0.05).CH 13 had the longest ASI, while EXP 2 negative ASI which mostly desirable under drought stress.

4.8 Mean agronomic performance of 25 genotypes used in the study.

The genotypes were ranked based on grain yield performance. Across-site data for the top 4 performing ultra-early maize hybrids are presented in Table 4.3. The maize hybrids were selected at 12% selection pressure. The EXP 5 was the best-performing hybrid across sites, with a mean grain yield of 2.14t/ha and a shelling percentage of 81.97%. It was followed by hybrid CH 5 with a grain yield of 2.06 t/ha and a shelling percentage of 83.67%. The results showed that EXP5 outperformed the best commercial check in terms of grain yield performance. Check hybrid 15 (0.96t/ha), Check hybrid 10(1.04t/ha), and Check hybrid 2 (1.09t/ha) were the least performing cultivars in the study(Table 4.3).

The hybrid designated as EXP 2 was the earliest hybrid in terms of days to silking (60.18 days) and days to anthesis (60.11 days) among all hybrids used in the study. Check hybrid 5 and EXP 2 were the best in terms of root lodging and stalk lodging among all the hybrids, with a total lodging of 1.7 % and 2.5%, respectively. This implies that the cultivars have good standability. The EXP 5 had the shortest plant height(2.22m), and EXP 2 had the highest plant height(2.55m) among the hybrids used in the study. The check hybrid 2,10,15 had the lowest fertility of 0.51,0.49, and 0.70, respectively, among the hybrids used in the study.

4.8 Ranking of ultra early maize hybrids based on performance across all sites

Rank	Genotype	Entry	NP	AD	SD	ASI	PH	EH	EHP	TL	FLT	GY	SH%
			The top 4 best-performing maize hybrids across sites										
1	EXP5	16	37.4	59.67	61.6	1.76	2.22	1.09	26.4	6.69	0.78	2.14	81.97
2	CH5	5	33.73	58.44	61	2.40	2.46	1.06	25.2	1.7	0.84	2.08	83.67
3	EXP7	18	34.8	59.33	61.4	2.04	2.43	0.99	28.8	2.76	0.86	2.07	84.63
4	EXP2	13	33.73	60.11	60.2	-0.11	2.55	1.20	26.4	6.19	0.81	2.05	82.35
Mean			34.92	59.39	61.03	1.52	2.42	1.08	26.71	4.33	0.82	2.09	83.16
P-Mean			31.79	61.56	63.53	1.68	2.41	1.14	21.51	8.97	0.73	1.60	81.84
LSD(0.005)			2.12	0.92	1.12	0.86	0.08	0.06	2.49	8.87	0.10	0.20	2.40
SED			4.18	1.82	2.23	1.70	0.17	0.12	4.92	17.59	0.20	0.40	4.73
CV%			18.27	3.16	3.62	101.81	7.41	11	31.5	203.5	33.29	38	8.69
			The top 4 selected best-performing maize hybrids across site										
Rank	Genotype	Entry											
1	EXP5	16	37.4	59.67	61.6	1.76	2.22	1.09	26.4	6.69	0.78	2.14	81.97
2	EXP7	18	34.8	59.33	61.4	2.04	2.43	0.99	28.8	2.76	0.86	2.07	84.63
3	EXP2	13	33.73	60.11	60.2	-0.11	2.55	1.20	26.4	6.19	0.81	2.05	82.35
4	EXP9	20	28.4	64.22	65.9	2.53	1.19	22	7.11	1.001	0.72	1.99	83.45
Mean			33.58	60.83	62.26	1.56	2.10	6.25	22.19	4.16	0.79	2.06	83.10
P-Mean			31.79	61.56	63.53	1.68	2.41	1.14	21.51	8.97	0.73	1.60	81.84
LSD(0.005)			2.12	0.92	1.12	0.86	0.08	0.06	2.49	8.87	0.10	0.20	2.40
SED			4.18	1.82	2.23	1.70	0.17	0.12	4.92	17.59	0.20	0.40	4.73
CV%			18.27	3.16	3.62	101.81	7.41	11	31.5	203.5	33.29	38	8.69
			Overall bottom 5 across sites										
Rank	Genotype	Entry											
21	CH9	9	28.8	62.67	65.8	2.17	2.39	1.09	21.2	7.80	0.83	1.17	81.76
22	CH8	8	26.6	63.89	66.5	2.61	2.31	1.11	18.1	21.29	0.75	1.10	80.5
23	CH2	2	23.27	59	61.4	2.17	2.31	1.04	10.9	5.40	0.70	1.09	80.44
24	CH10	10	33.13	65	68.5	3.29	2.23	1.15	14.1	7.19	0.49	1.04	82.27
25	CH15	25	30.67	63.33	65.9	1.94	2.44	1.29	15.8	17.33	0.51	0.96	78.3

Mean	28.49	62.78	65.60	2.44	2.33	1.14	16.03	11.80	0.66	1.07	80.65
P-Mean	31.79	61.56	63.53	1.68	2.41	1.14	21.51	8.97	0.73	1.60	81.84
LSD(0.005)	2.12	0.92	1.12	0.86	0.08	0.06	2.49	8.87	0.10	0.20	2.40
SED	4.18	1.82	2.23	1.70	0.17	0.12	4.92	17.59	0.20	0.40	4.73
CV%	18.27	3.16	3.62	101.8	7.41	11	31.5	203.5	33.3	38	8.69

AD=days to anthesis, SD=days to silking , PH=plant height(cm),EH=ear height,EHP=ears harvested per plot, TL=total lodging=fertility, GY=grain yield , SH%=shelling percentage, LSD=least significant difference at 5%,SE=standard error, CV= coefficient variation.

4.9 Realised genetic gains and selection of best maize hybrids

The data on realised genetic gains are shown in Table 4.4. Realised genetic gains achieved were measured focusing on the mean of selected hybrids against the mean population, the mean of the best check, and the mean of all checks in this study. The four best-performing newly developed ultra-early maturing maize hybrids were selected. There was a positive realised genetic gain of selected ultra early maize hybrids over the population mean for most traits except for AD, SD, EH, and TL. The mean grain yield of selected hybrids (EXP 5, EXP7, EXP2, EXP9) was 2.1t, and was much greater than the mean grain yield of the population mean before selection (1.6t). There was a 28.8% gain in grain yield of selected hybrids over the population mean before selection. Moreover, positive realised genetic gains were obtained on selected hybrids over the mean performance of the best commercial check on most of the traits, except for NP, PH, FLT, GY, and SH. However, there was a negative realised genetic gain on grain yield of -1% on selected hybrids over the best commercial check. The selected hybrids showed a positive realised genetic gain on grain yield with a 38.5% gain over the mean of all commercial checks. They also showed positive genetic gains on fundamental drought-tolerant traits such as anthesis to silking interval, and fertility with 36.1% and 10.7 % gain, respectively, over the mean of all checks.

4.9 Top ten hybrids and realised genetic gains of selected hybrids

GENOTYPE	ENTRY	NP	AD	SD	PH	EH	EHP	TL	ASI	FLT	FW	GW	MOI	GY	SH%
EXP5	16	37.4	59.7	61.6	2.2	1.1	26.4	6.7	1.8	0.8	2.0	1.6	14.6	2.1	82.0
CH5	5	33.7	58.4	61.0	2.5	1.1	25.2	1.7	2.4	0.8	1.9	1.6	13.7	2.1	83.7
EXP7	18	34.8	59.3	61.4	2.4	1.0	28.8	2.8	2.0	0.9	1.9	1.6	14.5	2.1	84.6
EXP2	13	33.7	60.1	60.2	2.6	1.2	26.4	6.2	-0.1	0.8	1.8	1.6	13.8	2.1	82.4
EXP9	20	28.4	64.2	65.9	2.5	1.2	21.7	7.1	1.0	0.7	1.9	1.5	14.9	2.0	83.5
CH4	4	32.7	62.4	63.5	2.4	1.2	23.7	6.7	0.3	0.8	1.8	1.5	14.0	2.0	85.4
EXP6	17	30.8	62.1	64.2	2.3	1.2	23.8	14.9	1.9	0.9	1.8	1.5	14.6	2.0	83.1
CH3	3	34.1	60.7	62.9	2.5	1.2	25.4	4.7	2.1	0.9	1.8	1.5	14.4	1.9	82.7
EXP3	14	30.9	63.1	64.2	2.6	1.2	21.9	16.0	1.0	0.8	1.7	1.4	14.1	1.8	82.1
CH1	1	34.4	58.1	58.5	2.5	1.0	24.0	3.1	0.1	0.9	1.7	1.3	13.6	1.7	78.4
Mean of selected hybrids		33.6	60.8	62.3	2.4	1.1	25.9	5.7	1.2	0.8	1.9	1.6	14.5	2.1	83.1
Grand mean /P-Population		31.8	61.6	63.5	2.4	1.1	21.5	9.0	1.7	0.7	1.5	1.2	14.2	1.6	81.8
Mean of the best check		33.7	58.4	61.0	2.5	1.1	25.2	1.7	2.4	0.8	1.9	1.6	13.7	2.1	83.7
Means of checks		31.3	61.4	63.6	2.4	1.1	20.4	8.6	1.8	0.7	1.4	1.1	14.1	1.5	81.8
Realised genetic gains															
Genetic gains over(MP)		5.6%	-1.2%	-2.0%	0.9%	-2.4%	20.2%	-36.6%	-30.2%	9.3%	25.8%	29.0%	1.5%	28.8%	1.5%
Genetic gains over MBC		-0.4%	4.1%	2.1%	-1.1%	5.6%	2.7%	234.5%	-51.1%	-5.6%	0.3%	0.3%	5.5%	-1.0%	-0.7%
Genetic gains over checks		7.4%	-1.0%	-2.1%	1.6%	-1.5%	26.7%	-33.9%	-36.1%	10.7%	34.3%	39.2%	2.3%	38.5%	1.6%

*- hybrids selected based on grain yield and stability; GY- grain yield (tha-1); ASI-anthesis silking interval; AD-days to mid pollen; SD-days to mid silking; ED-ear diameter (cm); EH-ear height (cm); SH-shelling percentage (%); TL-total lodging, FLT-fertility, FW-Field weight, MOI-Moisture content, NP-Number of plants, PH-Plant height, GW-grain weight.

CHAPTER 5

5.0 DISCUSSION OF RESULTS

5.1 Agronomic mean performances and genetic variation among hybrids.

The study revealed the agronomic potential of the ultra-early maturing varieties across diverse environments in the country. Significant differences in grain yield and related agronomic traits ($p<0.05$) were observed among genotypes across environments(see Appendices 16 and 17). A similar trend of results has been found by (Oyekunle *et al*., 2017). The significant difference among genotypes shows that there was a high genetic diversity for the traits measured. The presence of genetic diversity makes selection more effective for the advancement of maize cultivars with desired agronomic traits. The genetic diversity is expected to increase the level of realised genetic gains in the study.

The response of hybrids to different environmental conditions is a major challenge in identifying superior cultivars that are stable across environments (Badu-Apraku, B *et al*.,2017). The significant interactions between hybrids x environments for grain yield, and most measured traits ($p<0.05$) across sites(see Appendices 16 and 17) show that the testing sites were unique and showed enough genetic diversity among the ultra-early maize hybrids. The results corroborate with the findings of (Badu-Apraku *et al.*,2013), who observed the same trend. It also proves that varying levels of constraints, such as drought, were influential in the expression of traits. Contrarily lack of significant genotype x environment interaction on fertility, anthesis date, ear height, total lodging, shelling percentage, and moisture content indicates that these traits might be consistent in varying environmental conditions.

The significant variation in grain yield and most traits in environments indicates that the environment had a substantial impact on the expression of these traits. Earlier authors also reported significant effects of environment on grain yield and some related traits(Mickelson *et al.*,2001; Doerksen *et al.*,2003). Factors such as varying levels of drought stress, different soil types in testing environments, and solar radiation might have influenced the expression of these traits. Significant variation observed in the environment /replication ($p<0.05$) in most of the measured traits proves that soil conditions, such as pH and fertility, varied in each testing environment, which might have influenced the performance of these genotypes. However non non-significant variation was observed on environment /replication in traits such as silking date, ASI, total lodging, and moisture content, indicating that the same environment had no influence on expression of these traits in the study.

More so, highly significant variation on genotype in flowering dates (DMP and DMS), anthesis to silking interval (ASI) (see Appendix 16), indicated that hybrids were different in earliness. The EXP2 (-1 day) had a negative ASI, meaning that it was the earliest hybrid. This also permitted the hybrid to perform well in other agronomic parameters, including grain yield. The accelerated flowering synchrony is related to grain yield under drought stress (Das *et al*.,2018). Plants with shorter ASI tend to be more drought tolerant as they synchronise pollen and silk emergence, escaping moisture stress, which is mostly damaging at flowering. Plant breeders can use this hybrid in other breeding programs when breeding for earliness.

Farmers desire maize cultivars that are less prone to lodging. In such, maize breeders have targeted lodging resistance in maize genotypes. Total lodging was significantly affected by the environment only in the study(see Appendix 7). This might be due to the prevalence of strong winds in certain environments and different soil structures (as good soil structure supports plant anchorage) that have influenced plant lodging. Plant height, plant ratio and ear contribute to lodging resistance. In the study, EXP and CH5 (Table 4.3) were among the highest yielding genotypes with lower plant lodging. The EXP5 had the shortest plant height (2.2) and was the highest yielding in the study. This so because plants that are less vulnerable to lodging yield better as compared to the susceptible ones. Therefore, plant height is an important trait that is correlated with grain yield under drought stress (Yan *et al*., 2016). Similarly, genetic variation in terms of grain moisture content at harvest has also contributed to the selection of EXP5(14.6%), CH5(13.7%)and EXP2(14.6%) as the best yielding hybrids. The check 4 (15%) had the highest moisture content at harvest(see Appendix 15). This is not desirable because it can increase costs to farmers. High moisture content at harvest increases production costs to farmers due to increased energy requirements in artificial drying(Filipenco *et al*.,2013).

5.2 Mean grain yield performance of 25 genotypes across all sites

The mean grain yield performance among the hybrids in the study was influenced by three main factors: the hybrid itself, environment, and genotype x environment interaction. Almost all experimental hybrids had higher performance on grain yield and other desirable traits than the benchmark commercial hybrids, suggesting the potential for identifying and commercialising new sets of commercial hybrids in Zimbabwe. The hybrids were ranked in ascending order based on grain yield performance across testing sites(Table 4.3). The top 4 were dominated by experimental hybrids, and EXP 5 had the highest grain yield(2,14t/ha). EXP 2, EXP7 and EXP 9 performed well also, which qualified them for advancement to the next stage for evaluation. These hybrids exhibit promise for commercialisation in the country, as they are not only drought escape as being ultra-early maize hybrids but have the inherent ability to tolerate drought occurring throughout the season. These genotypes could be carrying desirable grain yield and agronomic traits. The advantages of newly developed stress-tolerant hybrids in grain yield and other important traits have been previously reported by various researchers (Setimela *et al.*,2017; Worku *et al.*,2020 & Menkir *et al*.,2022).

In contrast, commercial check varieties dominated the overall bottom 5, where there was no experimental hybrid. These genotypes, such as CH9, CH2, CH15 and CH8, produced low grain yield(Table 4.3). Similar results were reported by Cooper and Mark (2014), where the new drought-tolerant varieties outcompeted the commercial checks. The results are expected to affect realised genetic gains, where significant gains on grain yield of selected hybrids over check hybrids could be obtained. The high performance of newly developed ultra-early maize hybrids over commercial hybrids can be attributed to the development of plants with high heterosis compared to the available cultivars. Modern breeding techniques, such as marker-assisted selection, have aided plant breeders in exploiting heterosis (Lema, 2018). Farmers desire hybrids that can yield better even in situations of drought to ensure food security at home. Therefore, the newly developed maize cultivars have the potential to be released and adopted by farmers for grain improvement, especially by those in drought-prone areas.

5.2 Realised genetic gains of selected hybrids over check hybrids

The value of newly developed maize hybrids can be assessed based on their performance compared to commercial hybrids and the average yield of the population. In such higher realised genetic gains on the population mean and mean of all checks imply that the adoption of selected ultra-early maize hybrids can improve grain yield and agronomic traits (Table 4.4). Genetic gains help breeders to redefine and implement effective breeding techniques (Eriksson *et al*., 2018).

Table 4.4 presents the realised genetic gains of the top ten selected maize hybrids. Positive realised genetic gains were obtained in the study for grain yield and most of the measured traits. The mean grain yield of selected hybrids (EXP5, EXP7, EXP2, and EXP9) was 2.1t/ha, which was greater than the population mean(1.6t/ha) and the mean of all commercial checks (1.5t/ha). Therefore, the newly developed ultra-early can accelerate grain yield by 38.5% and 28.8% over commercial checks and population mean, respectively. The results are consistent with previous experimental results, which reported a 26-46% yield advantage of DT under drought stress(Fisher *et al*., 2015). Genetic gains have also been reported in maize hybrids developed from 2000 to 2010 in ESA (Masuka *et al*.,2017). The realised genetic gains indicated that the newly developed ultra-early hybrids might have a high commercial value for cultivation in the country.

The realised genetic gains were a result of the development of high-yielding maize genotypes that possess better agronomic and physiological traits associated with high yield potential under stressful conditions. Cattivelli and Luigi, (2008) reported the importance of agronomic and physiological traits in contributing to genetic gains under drought stress. The genetic gains in the study are also attributed to continued investment in breeding programs by private breeding companies in the country, which has allowed expansion of the phenotyping network and implementation of innovative breeding tools and technologies. Expansion of testing networks to diverse testing environments in the country has led to improved selection accuracy for fundamental traits(Messina *et al.,* 2023). However, negative realised genetic gains were obtained on the anthesis date, silking date, ear height, and total lodging on experimental hybrids over checks in the study. This suggests the influence of drought stress on the expression of these traits. It also implies the need for continuous breeding efforts to improve the performance of traits under drought.

CHAPTER 6

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The study showed a significant difference in grain yield potential among the ultra-early maize hybrids evaluated. There was a variability in agronomic performance among the ultra-early maize hybrids in the study. Significant realised genetic gains were also observed in the study on newly developed ultra-early maize hybrids over check hybrids. The realised genetic gain on grain yield was 28.8% above the population mean before selection, and it was also 38.5% over the mean of all commercial checks. The best-performing genotypes in the study were EXP5, CH5, EXP7, and EXP2. The EXP 5(2.1t/ha) outperformed all the hybrids in the study. The study proved that the newly developed ultra-early maturing maize cultivars can be useful for adoption by farmers. The significant variation for grain yield and agronomic traits in the study shows that the selection for superior genotypes for advancement can be effective. The realised genetic gains over the population mean and the mean of all commercial checks signify that the selected hybrids have a commercial value. Generally, the newly developed ultra-early maize hybrids performed better compared to commercial hybrids. The overall bottom 5 was dominated by commercial hybrids. Positive genetic gains were obtained over the mean of the population, the mean of best commercial checks, and the mean of all checks, except for a few traits.

6.2 Recommendations

Superior ultra-early maize genotypes such as EXP5, EXP7, EXP2, and EXP9 selected for their high yield performance should be advanced for release and further testing in drought-prone areas. Moreover, continuous investment is required to realise progress in terms of genetic gains in maize breeding programs. The investment will enable the incorporation of innovative breeding tools and technologies that will help achieve higher genetic gains. It will facilitate the continuous utilisation of expanded germplasm testing networks in targeted populations of environments to improve selection efficiency. The realised genetic gains need to be translated into gains for farmers through the replacement of old varieties with new, productive ones. This can help to improve maize production in targeted drought-prone environments.

REFERENCES

Ala-Kokko, K. et al. Economic and ecosystem impacts of GM maize in South Africa. *Glob. Food Security* **29**, 100544. https://doi.org/10.1016/j.gfs.2021.100544 (2021).

Anyango, John J., et al. "Termite-induced injuries to maize and baby corn under organic and conventional farming systems in the Central Highlands of Kenya." *Insects* 10.10 (2019): 367.

Araus, J. L., Serret, M. D., and Edmeades, G. (2012). Phenotyping maize for adaptation to drought. *Front. Physiol.* 3:305. doi: 10.3389/fphys.. 2012.00305.

Abadassi, Justin. "Maize agronomic traits needed in the tropical zone." *International Journal of Science, Environment and Technology* 4.2 (2015): 371-392.

Adrienn, et al. "The impact of environmental factors on the protein content and yield of maize grain at different nutrient supply levels." *Emirates Journal of Food and Agriculture* 30.9 (2018): 764-777.

Batchelor, William D., et al. "Simulation of maize lethal necrosis (MLN) damage using the CERES-maize model." *Agronomy* 10.5 (2020): 710.

Baudron, Frédéric, et al. "Projecting the contribution of provitamin A maize biofortification and other nutrition interventions to the nutritional adequacy and cost of diets in rural Zimbabwe." *The Journal of Nutrition* 154.6 (2024): 1815-1826.

Badu-Apraku, Ba, M. A. B. Fakorede, and Springer Cham. "Advances in genetic enhancement of early and extra-early maize for sub-Saharan Africa." (2017): 427-452.

Badu-Apraku, B.; Yallou, C.G.; Obeng-Antwi, K.; Alidu, H.; Talabi, A.O.; Annor, B.; Oyekunle, M.; Akaogu, I.C.; Aderounmu, M. Yield gains in extra-early maize cultivars of three breeding eras under multiple environments. J. Agron. 2017, 109, 1–14. [CrossRef]

Badu-Apraku, Baffour, et al. "Comparative performance of early-maturing maize cultivars developed in three eras under drought stress and well-watered environments in West Africa." *Crop Science* 53.4 (2013): 1298-1311.

Badu-Apraku, B.; Oyekunle, M. Genetic analysis of grain yield and other traits of extra-early yellow maize inbreds and hybrid performance under contrasting environments. Field Crops Res. 2012, 129, 99–110. [CrossRef]

Basu, Supratim, et al. "Plant adaptation to drought stress." *F1000Research* 5 (2016): F1000-Faculty.

Berger, Dave K., et al. "Mapping QTL conferring resistance in maize to grey leaf spot disease caused by Cercospora zeina." *BMC genetics* 15 (2014): 1-12.

Begna, T. (2021). Combining ability and heterosis in plant improvement. *Open Journal of Plant Science*, *6*(1), 108-117.

Blum, Abraham. "Drought resistance–is it really a complex trait?." *Functional Plant Biology* 38.10 (2011): 753-757.

Cattivelli, Luigi, et al. "Drought tolerance improvement in crop plants: an integrated view from breeding to genomics." *Field crops research* 105.1-2 (2008): 1-14.

Cooper, Mark, et al. "Breeding drought-tolerant maize hybrids for the US corn-belt: discovery to product." *Journal of Experimental Botany* 65.21 (2014): 6191-6204.

Das, B., Atlin, G. N., Olsen, M., Burgueño, J., Tarekegne, A., Babu, R., et al. (2018).Identification of donors for low-nitrogen stress with maize lethal necrosis (MLN)tolerance for maize breeding in sub-Saharan Africa. Euphyt 215, 80. doi: 10.1007/s10681–019-2406–5

Duvick, D.N. Genetic progress in yield of United States maize (Zea mays L.). Maydica 2005, 50, 193–202.

Doerksen, Trevor K., Lyn W. Kannenberg, and Elizabeth A. Lee. "Effect of recurrent selection on combining ability in maize breeding populations." *Crop science* 43.5 (2003): 1652-1658.

Shaolong, and Wei Xiong. "Weather extremes shock maize production: Current approaches and future research directions in Africa." *Plants* 13.12 (2024): 1585.

Ekpa, Onu, et al. "Sub-Saharan African maize-based foods-processing practices, challenges and opportunities." *Food Reviews International* 35.7 (2019): 609-639.

Erenstein, O., Chamberlin, J. & Sonder, K. Estimating the global number and distribution of maize and wheat farms. *Glob. FoSecurity* **30**, 100558. https://doi.org/10.1016/j.gfs.2021.100558 (2021).

Eriksson, D., Akoroda, M., Azmach, G., Labuschagne, M., Mahungu., N., Ortiz, R. (2018). Measuring the impact of plant breeding on sub-Saharan African staple crops. *Outlook Agric.* 47, 163–180. doi: 10.1177/0030727018800723.

Effendi, R., et al. "Drought adaptation level of maize genotypes based on leaf rolling, temperature, relative moisture content, and grain yield parameters." *IOP Conference Series: Earth and Environmental Science*. Vol. 270. No. 1. IOP Publishing, 2019

Epule, Terence Epule, Abdelghani Chehbouni, and Driss Dhiba. "Recent patterns in maize yield and harvest area across Africa." *Agronomy* 12.2 (2022): 374.

Eriksson, D., Akoroda, M., Azmach, G., Labuschagne, M., Mahungu., N., Ortiz, R. (2018). Measuring the impact of plant breeding on sub-Saharan African staple crops. *Outlook Agric.* 47, 163–180. doi: 10.1177/0030727018800723

FAO-ESS. (2021). Crops Statistics - Concepts, Definitions and Classifications. FAO Statistics Division(ESS),Rome. https://www.fao.org/economic/the-statistics-division-ess/methodology/methodology-systems/crops-statistics-concepts-definitions-and-classifications/en/

FAO (2020). Food and Agriculture Organisation of the United Nations. Rome,FAOSTAT database

FAO (2013) Food and Agriculture Organisation of the United Nations. Rome,FAOSTAT database

FAO (2023). Food and Agriculture Organisation of the United Nations. Rome,FAOSTAT database

FAO (2024). Food and Agriculture Organisation of the United Nations. Rome,FAOSTAT database

Farooq, Ahsan, Nageen Farooq, Haseeb Akbar, Zia Ul Hassan, and Shabbir H. Gheewala. "A critical review of climate change impact at a global scale on cereal crop production." *Agronomy* 13, no. 1 (2023): 162.

Fisher, M., and Carr, E. R. (2015). The influence of gendered roles and responsibilities on the adoption of technologies that mitigate drought risk : the case of drought-tolerant maize seed in eastern Uganda. *Glob. Environ. Change* 35, 82–92. doi: 10.1016/j.gloenvcha.2015.08.009

Guyader, J., Baron, V. S., & Beauchemin, K. A. (2018). Corn forage yield and quality for silage in short growing season areas of the Canadian prairies. *Agronomy*, *8*(9), 164.

García-Lara, S., & Serna-Saldivar, S. O. (2019). Corn History and Culture. In: Serna-Saldivar, S.O. (Ed.), Corn (Third Edition). AACC International Press, Oxford, pp. 1–18. https://doi.org/10.1016/B978-0-12-811971-6.00001-2

Gowda, Manje, et al. "Genetic dissection of Striga hermonthica (Del.) Benth. Resistance via genome-wide association and genomic prediction in tropical maize germplasm." *Theoretical and Applied Genetics* 134 (2021): 941-958.

Grewer, Uwe, Dong-Hyuk Kim, and Katharina Waha. "Too much, too soon? Early-maturing maize varieties as drought escape strategy in Malawi." *Food Policy* 129 (2024): 102766.

https://www.seedcoonlineshop.com/zw/

Iqbal, S., Iqbal, M. A., Li, C., Iqbal, A., & Abbas, R. N. (2023). Overviewing drought and heat stress amelioration—from plant responses to microbe-mediated mitigation. *Sustainability*, *15*(2), 1671.

Jain, M., Barrett, C. B., Solomon, D., and Ghezzi-Kopel, K. (2023). Surveying the evidence on sustainable intensification strategies for smallholder agricultural systems. Ann. Rev. Environ. Resource. 48, 347–369. doi: 10.1146/annurev-environ-112320- 093911.

Karavina, Charles. "Maize streak virus: A review of pathogen occurrence, biology and management options for smallholder farmers." (2014).

Rahman, S.; Mia, M.M.; Quddus, T.; Hassan, L.; Haque, M.A. Assessing genetic diversity of maize (Zea mays L.) genotypes for agronomic traits. Res. Agric. Livest. Fish. 2015, 2, 53–61. [Google Scholar] [CrossRef]

Ranum, P., Peña-Rosas, J. P., & Garcia-Casal, M. N. (2014). Global maize production, utilization, and consumption. *Annals of the new York academy of sciences*, *1312*(1), 105-112.

Rodrigues, C. S., Gallo, P. B., Ticelli, M., & Paterniani, M. E. A. G. Z. (2021). Drought tolerance in intervarietal maize hybrids. *Revista Caatinga*, *34*(1), 80-89.

Kaur, R., Kaur, G., Vikal, Y., Gill, G. K., Sharma, S., Singh, J., ... & Chawla, J. S. (2020). Genetic enhancement of essential amino acids for nutritional enrichment of maize protein quality through marker assisted selection. *Physiology and Molecular Biology of Plants*, *26*, 2243-2254.

Khaeim, H., Kende, Z., Jolánkai, M., Kovács, G. P., Gyuricza, C., & Tarnawa, Á. (2022). Impact of temperature and water on seed germination and seedling growth of maize (Zea mays L.). *Agronomy*, *12*(2), 397.

Kosova, K., Vitamvas, P., Urban, M. O., Kholova, J., and Prášil, I. T. (2014). Breeding for enhanced drought resistance in maize and wheat-drought-associated traits, genetic resources and their potential utilisation in breeding programmes. *Czech J. Genet. Plant Breed.* 50, 247–261. doi: 10.17221/118/2014-cjgpb.

Kosova, K., Vitamvas, P., Urban, M. O., Kholova, J., and Prášil, I. T. (2014). Breeding for enhanced drought resistance in maize and wheat-drought-associated traits, genetic resources and their potential utilisation in breeding programmes. *Czech J. Genet. Plant Breed.* 50, 247–261. doi: 10.17221/118/2014-cjgpb.

Koffi, Djima, et al. "Assessment of impacts of fall armyworm, Spodoptera frugiperda (Lepidoptera: Noctuidae) on maize production in Ghana." *Journal of Integrated Pest Management* 11.1 (2020): 20

Kumela, T., Mendesil, E., Enchalew, B., Kassie, M. and Tefera, T., 2019. Effect of the push-pull cropping system on maize yield, stem borer infestation and farmers' perception. *Agronomy*, *9*(8), p.452.

Kunle, Olobayo O. "Starch source and its impact on pharmaceutical applications." *Chemical Properties of Starch* 35 (2019).

Lakshmi, G. A., Krishna, G. K., Patni, B., Prakash, S., Bhattacharyya, M., ... & Verma, K. K. (2022). Climate change and its impact on crops: A comprehensive investigation for sustainable agriculture. *Agronomy*, *12*(12), 3008.

Laude, T.P. and Carena, M.J., 2015. Genetic diversity and heterotic grouping of tropical and temperate maize populations adapted to the northern US Corn Belt. *Euphytica*, *204*, pp.661-677.

Lybbert, T. J., and Sumner, D. A. (2012). Agricultural technologies for climate change in developing countries: policy options for innovation and technology diffusion. Food Policy 37, 114–123. doi: 10.1016/j.foodpol.2011.11.001

Lema, M. (2018). Marker assisted selection in comparison to conventional plant breeding. *Agric Res Technol*, *14*, 555914.

Li, YeBei, et al. "Effect of drought on ear development and yield of maize." *Chinese Journal of Eco-Agriculture* 23.4 (2015): 383-391.

Louw, André, et al. "Determining the factors that limit agro-processing development in the maize milling industry in rural areas in South Africa." *Report by Markets and Economics Research Centre (MERC) for the National Agricultural Marketing Centre (NAMC), South Africa* (2010).

Masuka, B., Magorokosho, C., Olsen, M., Atlin, G. N., Bänziger, M., Pixley, K., et al. (2017b). Gains in maize genetic improvement in Eastern and Southern Africa ii) CIMMYT open-pollinated varieties (OPVS) breeding pipeline. Crop Sci. 57, 180–191. doi: 10.2135/cropsci2016.05.0408.

Maazou, Abdoul-Raouf Sayadi, et al. "Breeding for drought tolerance in maize (Zea mays L.)." *American Journal of Plant Sciences* 7.14 (2016): 1858.

Maitra, S.,& Banerjee, P. (2020). Potential and Advantages of Maize-Legume Intercropping. *Maize: Production and Use*, 103.

M.Bänziger, G.O. Edmeades and H.R. Lafitte: Selection for drought tolerance increases maize yields over a range of N levels. Crop Science 39, 1035-1040. 1999.

Oyekunle, A. Haruna, B. Badu-Apraku, I.S. Usman, H. Mani, S.G. Ado, G. Olaoye, K. Obeng-Antwi, R.O. Abdulmalik, H.O. Ahmed, Assessment of early maturing maize hybrids and testing sites using GGE biplot analysis, Crop Sci. 57 (6) (2017) 2942–2950, https://doi.org/10.2135/cropsci2016.12.1014

Menkir, A., Dieng, I., Meseka, S., Bossey, B., Mengesha, W., Muhyideen, O., et al. (2022). Estimating genetic gains for tolerance to stress combinations in tropical maize hybrids. Front. Genet. 13. doi: 10.3389/fgene.2022.1023318

Menkir, Abebe, et al. "Mitigating Striga hermonthica parasitism and damage in maize using soybean rotation, nitrogen application, and Striga-resistant varieties in the Nigerian savannas." *Experimental agriculture* 56.4 (2020): 620-632.

Messina, C. D., Gho, C., Hammer, G. L., Tang, T., & Cooper, M. (2023). Two decades of harnessing standing genetic variation for physiological traits to improve drought tolerance in maize. *Journal of experimental botany*, *74*(16), 4847-4861.

Muthuvel, D. K., Sivakumar, B., and Mahesha, A. (2023). Future global concurrent droughts and their effects on maize yield. Sci. Total Environ. 855, 158860. doi: 10.1016/ j.scitotenv.2022.158860.

Mushayi, Malven, et al. "Breeding for resistance to maize streak virus: challenges, progress and future directions: a review." *Frontiers in Plant Science* 16 (2025): 1590870.

Mickelson, Harold R., et al. "Heterotic relationships among nine temperate and subtropical maize populations." *Crop Science* 41.4 (2001): 1012-1020.

Nadeem, F., Rehman, A., Ullah, A., Farooq, M., & Siddique, K. H. (7). Managing Drought in Semi-Arid Regions through Improved Varieties and Choice of Species. *Managing Soil Drought*, 212-234.

Nasar, J., Zhao, C. J., Khan, R., Gul, H., Gitari, H., Shao, Z., ... & Yang, J. (2023). Maize-soybean intercropping at optimal N fertilization increases the N uptake, N yield and N use efficiency of maize crop by regulating the N assimilatory enzymes. *Frontiers in Plant Science, 13*, 1077948.

Nzuve, F., et al. "Combining abilities of maize inbred lines for grey leaf spot (GLS), grain yield and selected agronomic traits in Kenya." (2013).

Neiff, Nicolás, et al. "Physiological responses and post-stress recovery in field-grown maize exposed to high temperatures at flowering." *Australian Journal of Crop Science* 13.12 (2019): 2053-2061.

Ngugi, Kahiu, Juma Ogeto Collins, and Sicily Muchira. "Combining earliness, short anthesis to silking interval and yield-based selection indices under intermittent water stress to select for drought-tolerant maize." *Australian Journal of Crop Science* 7.13 (2013): 2014-2020.

Nuss, E. T., & Tanumihardjo, S. A. (2010). Maize: a paramount staple crop in the context of global nutrition. *Comprehensive reviews in food science and food safety*, *9*(4), 417-436.

Potopova, V., Boroneanţ, C., Boincean, B., & Soukup, J. (2016). Impact of agricultural drought on main crop yields in the Republic of Moldova. *International Journal of Climatology*, *36*(4), 2063-2082.

Prasanna, B. M., Cairns, J. E., Zaidi, P. H., Beyene, Y., Makumbi, D., Gowda, M., ... & Zhang, X. (2021). Beat the stress: breeding for climate resilience in maize for the tropical rainfed environments. *Theoretical and Applied Genetics*, *134*(6), 1729-1752.

Ranum, Peter, Juan Pablo Peña-Rosas, and Maria Nieves Garcia-Casal. "Global maize production, utilisation, and consumption." *Annals of the new York academy of sciences* 1312.1 (2014): 105-112.

Sallam, Ahmed, et al. "Genetic diversity and genetic variation in morpho-physiological traits to improve heat tolerance in Spring barley." *Molecular biology reports* 45 (2018): 2441-2453.

Savary, Serge, et al. "The global burden of pathogens and pests on major food crops." *Nature ecology & evolution* 3.3 (2019): 430-439.

Sánchez, Berta, Anton Rasmussen, and John R. Porter. "Temperatures and the growth and development of maize and rice: a review." *Global change biology* 20, no. 2 (2014): 408-417.

Schulthess, Albert Wilhelm, Yusheng Zhao, and Jochen C. Reif. "Genomic selection in hybrid breeding." *Genomic Selection for Crop Improvement: New Molecular Breeding Strategies for Crop Improvement* (2017): 149-183.

Simmons, C. R., Lafitte, H. R., Reimann, K. S., Brugière, N., Habben, J. E. (2021). Successes and insights of an industry biotech program to enhance maize agronomic traits. *Plant Sci.* 307, 110899. doi: 10.1016/j.plantsci.2021.110899.

Setimela, P. S., Magorokosho, C., Lunduka, R., Gasura, E., Makumbi, D., Tarekegne, A., et al. (2017). On-farm yield gains with stress-tolerant maize in Eastern and Southern Africa. Agron. J. 109, 406–417. doi: 10.2134/agronj2015.0540.

Samuel, et al. "Identification of QTL for early vigour and stay-green conferring tolerance to drought in two connected advanced backcross populations in tropical maize (Zea mays L.)." *PloS one* 11.3 (2016): e0149636.

Ten Berge, Hein FM, et al. "Maize crop nutrient input requirements for food security in sub-Saharan Africa." *Global Food Security* 23 (2019): 9-21.

Tesfaye, Kindie, et al. "Potential benefits of drought and heat tolerance for adapting maize to climate change in tropical environments." *Climate risk management* 19 (2018): 106-119.

Ullah, Z., Rahman, H., & Muhammad, N. (2017). Evaluation of maize hybrids for maturity and related traits. *Sarhad Journal of Agriculture*, *33*(4), 624-629.

Umar, U. U., et al. "Studies on genetic variability in maize (Zea mays L.) under stress and non-stress environmental conditions." *International Journal of Agronomy and Agricultural Research* 7.1 (2015): 70-77.

Worku, M., DeGroote, H., Munyua, B., Makumbi, D., Owino, F., Crossa, J., et al. (2020). On-farm performance and farmers' participatory assessment of new stress-tolerant maize hybrids in Eastern Africa. Field Crops Res. 246, 107693. doi: 10.1016/ j.fcr.2019.107693.

www.seedcoonlineshop.com

www.cimmyt.org

www.pannar.com

Yan, Weiming, Yangquanwei Zhong, and Zhouping Shangguan. "Evaluation of physiological traits of summer maize under drought stress." *Acta Agriculturae Scandinavica, Section B—Soil & Plant Science* 66.2 (2016): 133-140.

Zhao, Yating, et al. "Optimizing ear-plant height ratio to improve kernel number and lodging resistance in maize (Zea mays L.)." *Field Crops Research* 276 (2022): 108376.

Zhao C, Liu B, Piao S, Wang X, Lobell DB, Huang Y, ... Asseng S (2017). Temperature increase reduces global yields of major crops in four independent estimates. Proceedings of the National Academy of Sciences 114(35):9326-9331. https://doi.org/10.1073/pnas.170176211.

Ziyomo, C., & Bernardo, R. (2013). Drought tolerance in maize: Indirect selection through secondary traits versus genomewide selection. *Crop Science*, *53*(4), 1269-127

List of appendices

Appendix 1

Variate :NP

Acumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	4	27914.73	6978.68	206.97	<.001
ENV.REPL	10	3029.47	302.95	8.98	<.001
ENV.REPL.BLOCK	60	12066.16	201.1	5.96	<.001
ENTRY	24	3256.47	135.69	4.02	<.001
ENV.ENTRY	96	5628.13	58.63	1.74	<.001
Residual	180	6069.4	33.72		
Total	374	57964.36	154.98		

Appendix 2

Variate :AD

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	2	775.796	387.898	102.65	<.001
ENV.REPL	6	66.8	11.133	2.95	0.011
ENV.REPL.BLOCK	36	436.32	12.12	3.21	<.001
ENTRY	24	748.309	31.18	8.25	<.001
ENV.ENTRY	48	249.958	5.207	1.38	0.087
Residual	108	408.133	3.779		
					89.19019
Total	224	2685.316	11.988		

Appendix 3

Variate :SD

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	2	573.749	286.874	54.8	<.001
ENV.REPL	6	42.713	7.119	1.36	0.239
ENV.REPL.BLOCK	36	474.57	13.182	2.52	<.001
ENTRY	24	864.104	36.004	6.88	<.001
ENV.ENTRY	48	406.186	8.462	1.62	0.024
Residual	94	492.043	5.234		
Total	210	2853.365	13.587		

Appendix 4

Variate:ASI

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	2	109.358	54.679	17.92	<.001
ENV.REPL	6	3.175	0.529	0.17	0.983
ENV.REPL.BLOCK	36	141.006	3.917	1.28	0.17
ENTRY	24	136.33	5.68	1.86	0.018
ENV.ENTRY	48	170.302	3.548	1.16	0.264
Residual	94	286.767	3.051		
Total	210	846.938	4.033		

Appendix 5

Variate :PH

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	2	29.79282	14.89641	466.45	<.001
ENV.REPL	6	0.95528	0.15921	4.99	<.001
ENV.REPL.BLOCK	36	3.95425	0.10984	3.44	<.001
ENTRY	24	2.61927	0.10914	3.42	<.001
ENV.ENTRY	48	2.73355	0.05695	1.78	0.007
Residual	108	3.44903	0.03194		
Total	224	43.50418	0.19422		

Appendix 6

Variate:EH

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	2	10.08405	5.04203	302.91	<.001
ENV.REPL	6	0.46247	0.07708	4.63	<.001
ENV.REPL.BLOCK	36	1.15882	0.03219	1.93	0.005
ENTRY	24	1.27597	0.05317	3.19	<.001
ENV.ENTRY	48	1.00321	0.0209	1.26	0.166
Residual	108	1.7977	0.01665		
Total	224	15.78222	0.07046		

Appendix.7

Variate:TL

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	2	1972.6	986.3	2.9	0.04
ENV.REPL	6	3477.7	579.6	1.7	0.128
ENV.REPL.BLOCK	36	14524.3	403.5	1.18	0.253
ENTRY	24	7267.2	302.8	0.89	0.616
ENV.ENTRY	48	15109.5	314.8	0.92	0.613
Residual	101	34408.1	340.7		
Total	217	76759.5	353.7		

Appendix 8

Variate :Fertility

Change	d.f.	s.s.	m.s.	v.r.	F pr.

ENV	3	1.53669	0.51223	8.79	<.001
ENV.REPL	8	2.11577	0.26447	4.54	<.001
ENV.REPL.BLOCK	48	5.95022	0.12396	2.13	<.001
ENTRY	24	3.07342	0.12806	2.2	0.002
ENV.ENTRY	72	5.26296	0.0731	1.25	0.127
Residual	141	8.21614	0.05827		
Total	296	26.1552	0.08836		

Appendix 9

Variate :GW

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	5	119.8281	23.9656	112.02	<.001
ENV.REPL	12	15.04	1.2533	5.86	<.001
ENV.REPL.BLOCK	72	41.0995	0.5708	2.67	<.001
ENTRY	24	31.5739	1.3156	6.15	<.001
ENV.ENTRY	120	42.1213	0.351	1.64	<.001
Residual	205	43.8571	0.2139		
Total	438	293.5199	0.6701		

Appendix 10

Variate :MOI

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	5	1184.562	236.912	117.33	<.001
ENV.REPL	12	24.729	2.061	1.02	0.431

ENV.REPL.BLOCK	72	182.102	2.529	1.25	0.113
ENTRY	24	64.048	2.669	1.32	0.153
ENV.ENTRY	120	227.733	1.898	0.94	0.643
Residual	205	413.94	2.019		
Total	438	2097.114	4.788		
Total	438	29448.14	67.23		52.61775

Appendix 11

Variate:GY

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	5	205.5876	41.1175	115.51	<.001
ENV.REPL	12	25.0782	2.0898	5.87	<.001
ENV.REPL.BLOCK	72	68.3882	0.9498	2.67	<.001
ENTRY	24	54.8009	2.2834	6.41	<.001
ENV.ENTRY	120	71.5721	0.5964	1.68	<.001
Residual	206	73.3269	0.356		
Total	439	498.7538	1.1361		

Appendix 12

Variate :FW

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	5	180.2705	36.0541	93.96	<.001

ENV.REPL	12	21.5226	1.7935	4.67	<.001
ENV.REPL.BLOCK	72	59.0456	0.8201	2.14	<.001
ENTRY	24	37.5972	1.5665	4.08	<.001
ENV.ENTRY	120	73.4678	0.6122	1.6	0.002
Residual	205	78.6612	0.3837		
Total	438	450.5649	1.0287		

Appendix 13

Variate :EHP

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	4	7401.2	1850.3	40.63	<.001
ENV.REPL	10	2252.54	225.25	4.95	<.001
ENV.REPL.BLOCK	60	7038.26	117.3	2.58	<.001
ENTRY	24	5968.91	248.7	5.46	<.001
ENV.ENTRY	96	6437.08	67.05	1.47	0.014
Residual	173	7877.56	45.54		
Total	367	36975.55	100.75		

Appendix 14

Variate :SH%

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
ENV	5	5695.25	1139.05	22.56	<.001
ENV.REPL	12	1180.17	98.35	1.95	0.031

ENV.REPL.BLOCK	72	3832.12	53.22	1.05	0.381
ENTRY	24	1345.97	56.08	1.11	0.334
ENV.ENTRY	120	7042.12	58.68	1.16	0.173
Residual	205	10352.5	50.5		
Total	438	29448.14	67.23		52.61775

Appendix 15

Across site means for all genotypes in the study.

GENOTYPE	ENTRY	NP	AD	SD	PH	EH	EHP	TL	ASI	FLT	FW	GW	MOI	GY	SH%
CH1	1	34.4	58.11	58.49	2.52	1.03	23.98	3.09	0.12	0.89	1.65	1.28	13.6	1.69	78.43
CH2	2	23.27	59	61.41	2.31	1.04	10.93	5.40	2.17	0.70	1.33	0.83	13.8	1.09	80.44
CH3	3	34.07	60.67	62.93	2.46	1.21	25.42	4.66	2.14	0.87	1.81	1.48	14.4	1.92	82.73
CH4	4	32.67	62.44	63.52	2.42	1.18	23.72	6.692	0.26	0.76	1.76	1.50	15	1.97	85.35
CH5	5	33.73	58.44	60.98	2.46	1.06	25.17	1.7	2.40	0.84	1.88	1.59	13.7	2.08	83.67
CH6	6	33.73	62.56	63.23	2.49	1.22	23.9	10.97	0.50	0.65	1.53	1.29	13.8	1.68	82.52
CH7	7	32.8	61.78	63.6	2.51	1.19	22.73	13.19	1.56	0.68	1.41	1.18	14.3	1.52	82.98
CH8	8	26.6	63.89	66.45	2.31	1.11	18.08	21.29	2.61	0.75	1.04	0.85	14.5	1.10	80.5
CH9	9	28.8	62.67	65.78	2.39	1.09	21.2	7.80	2.17	0.83	1.08	0.90	14.1	1.17	81.76
CH10	10	33.13	65	68.47	2.23	1.15	14.11	7.19	3.29	0.49	0.98	0.82	14.3	1.04	82.27
CH11	11	35.93	60.11	61.78	2.37	1.10	20.23	7.44	1.53	0.58	1.36	1.11	14.2	1.46	82.36
EXP1	12	31.47	63.22	64.87	2.39	1.21	20.18	22.05	1.35	0.65	1.26	1.01	13.7	1.32	78.44
EXP2	13	33.73	60.11	60.18	2.55	1.20	26.43	6.19	-0.11	0.81	1.82	1.56	13.8	2.05	82.35
EXP3	14	30.93	63.11	64.18	2.58	1.24	21.94	16.02	1.01	0.77	1.66	1.39	14.1	1.82	82.13
EXP4	15	33.8	59	61.1	2.34	1.12	23.75	3.85	2.06	0.74	1.52	1.21	14.6	1.49	79.36
EXP5	16	37.4	59.67	61.55	2.22	1.09	26.43	6.69	1.76	0.78	1.99	1.65	14.6	2.14	81.97
EXP6	17	30.8	62.11	64.16	2.32	1.16	23.81	14.89	1.91	0.86	1.81	1.51	14.6	1.96	83.1
EXP7	18	34.8	59.33	61.4	2.43	0.99	28.8	2.76	2.04	0.86	1.89	1.61	14.5	2.07	84.63
EXP8	19	31.8	63.22	64.46	2.57	1.18	21.16	11.25	0.65	0.63	1.50	1.24	14.2	1.62	83.67
EXP9	20	28.4	64.22	65.92	2.53	1.19	21.74	7.11	1.00	0.72	1.86	1.55	14.9	1.99	83.45

EXP10	21	32.67	63.44	66.51	2.45	1.21	17.59	4.41	2.82	0.57	1.14	0.95	15.1	1.20	80.22
CH12	22	31.8	62.78	65.14	2.45	1.24	22.23	8.87	2.04	0.74	1.40	1.14	14	1.48	81.18
CH13	23	30.47	61.89	64.9	2.47	1.16	18.27	13.45	2.65	0.64	1.45	1.18	15	1.52	81.51
CH14	24	26.87	59	61.44	2.12	0.95	20.18	-0.07	2.21	0.80	1.52	1.26	14.5	1.63	82.65
CH15	25	30.67	63.33	65.91	2.44	1.29	15.84	17.33	1.94	0.51	0.91	0.74	13.8	0.96	78.3
Means		31.79	61.56	63.53	2.41	1.14	21.51	8.97	1.68	0.73	1.50	1.23	14.24	1.60	81.84
SED		2.12	0.92	1.12	0.08	0.06	2.49	8.87	0.86	0.10	0.21	0.16	0.48	0.20	2.40
LSD		4.18	1.82	2.23	0.17	0.12	4.92	17.59	1.70	0.20	0.41	0.31	0.95	0.40	4.73
CV%		18.27	3.16	3.62	7.41	11.28	31.51	37.54	101.8	33.29	41.7	37.94	9.98	25.7	8.69

Figure 2.Appendix 16

Agronomic mean squares and significant tests for 25 genotypes across six sites

SOURCE	DF	AD	SD	ASI	PH	EH	TL	FLT	NP	EHP
Envi	6	387.90***	286.87***	54.68***	14.90***	5.04***	986.3*	0.51***	6978.68***	1850.3***
Envi /repl	12	11.13**	7.13ns	0.53ns	0.16***	0.08***	579.6ns	0.26***	302.95***	225.25***
Envi/repl /blck	72	12.12***	13.18***	3.92ns	0.11***	0.03**	403.5ns	0.12***	201.1***	117.3***
Genotype	24	31.18***	36.00***	5.68**	0.11***	0.05**	302.8ns	0.13**	135.69***	248.7***
G x E	120	5.21ns	8.46**	3.55*	0.06**	0.02ns	314.8ns	0.07ns	58.63***	67.05**
Residual	216	3.78	5.23	3.05	0.03	0.02	340.7	0.06	33.72	45.54
Total	449	11.99	13.59	4.03	0.19	0.07	353.7	0.09	154.98	100.75
Means		61.56	63.53	1.68	2.41	1.14	8.97	0.73	31.79	21.513
LSD 0.05		0.92	1.12	0.86	0.08	0.06	8.87	0.10	4.18	2.49

S.E	1.82	2.23	1.70	0.17	0.12	17.59	0.20	2.12	4.92
CV%	3.16	3.62	101.81	7.41	11.28	203.54	33.29	18.27	31.51

Appendix 17

Mean squares and significance for grain yield and related traits

SOURCE	**DF**	**FW**	**GW**	**MOI**	**GY**	**SH%**
Environment	5	36.05***	23.9***	236.91***	41.12***	1139.05***
Environment /replication	12	1.79***	1.25***	2.06ns	2.09***	98.35*
Environment/replication /block	72	0.82***	0.57***	2.52ns	0.95***	53.22ns
Genotype	24	1.57***	1.31***	2.67ns	2.28***	56.08ns
Genotype x environment	120	0.61**	0.35***	1.90ns	0.60***	58.68ns
Residual	216	0.38	0.21	2.02	0.36	50.50
Total	449	1.03	0.67	4.79	1.14	67.23
Means		1.50	1.23	14.24	1.60	81.84
LSD 0.05		0.21	0.16	0.48	0.20	2.40

S.E	0.41	0.31	0.95	0.40	4.73
CV%	41.69	37.94	9.98	25.67	8.69