BINDURA UNIVERSITY OF SCIENCE EDUCATION
FACULTY OF AGRICULTURE AND ENVIRONMENTAL SCIENCE
CROP SCIENCE DEPARTMENT

# AN INTERMEDIATE TESTCROSS PERFORMANCE OF STRESS TOLERANT MAIZE (ZEA MAYZ L) HYBRIDS UNDER STRESS AND NON-STRESS CONDITIONS

A DISSERTATION SUBMITTED IN PARTIAL
FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE

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# DECLARATION

I Gavhumende Tatenda E, registration B190043B declare that this research project is my own work and has not been raised or copied from any source without acknowledgement of source.

# DEDICATION

Firstly, I thank the Almighty for revealing me with better ideas and power. This research project is a dedication to my family especially my father Bothwell Gavhumende, I am grateful for all the motivations you raised towards me and for the financial support you rendered during my studies.

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# ABSTRACT

Estimates of testcross performance are critical for selecting suitable maize hybrids. The testcross performance of 22 stress tolerant hybrids (genotypes) were investigated in this study. The germplasm for all the testcross materials came from the Crop Breeding Institute. Eight check varieties from locally released maize varieties were used. In the summer and winter of 21/2022, eight checks together with 22 hybrids were evaluated in four different sites, both stressed and non-stressed. Significance in grain yield performance under non-stressed environments were observed (P<0.001). Also, significant grain yield performance of maize hybrids under stressed environments were observed (P<0.001). Hybrids (genotypes) 143WH705 and 143WH742 were high yielding and stable across environments and had performed above all checks. Hybrid 143WH728 was comparable in-terms of grain yield to 143WH705 and 143WH742 as well as the check SC725 under non-stress environment. Hybrids 143WH705 and 143WH742 were the best candidates to be grown under stressed environments while hybrid 143WH728 performed well under non-stress environments.

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| | |
|---|---|
| AEC | Average environmental coordinate line |
| EA | Ear aspect |
| EPP | Ears per plant |
| ER | Ear rots |
| GEI | Genotype by environment interaction |
| GGE | biplot Genotype-genotype x environment Biplots |
| GLS | Grey leaf spot |
| GY | grain yield |
| MDS | Managed Drought stress |
| PH | Plant height |
| SSA | Sub-Saharan Africa |
| DT | Drought Tolerant |
| MMT | Million metric tonnes |
| MLN | Maize Lethal necrosis |
| MCMV | Maize chlorotic mottle virus |
| FAW | Fall-army worm |
| ESA | Eastern and Southern Africa |
| ASI | Anthesis silking Interval |

| | |
|---|---|
| QTL | Quantitative trait loci |
| mQTL | meta Quantitative trait loci |
| GWAS | Genome-wide association mapping studies |
| SNP | Single nucleotide polymorphism |
| Gen | Genetic engineering |
| ROS | Reactive oxygen species |
| DPT | Drought tolerant population |
| DH | Doubled haploids |
| AMMI- | Additive main effect and multiplicative interaction |
| ANOVA | Analysis of variance |

# CHAPTER 1

## 1.0 INTRODUCTION

### 1.1 Background

Maize is one of the most important cereal crops in the world, ranking second only to wheat in terms of overall cereal grain production (Igyuve *et al.*, 2018). Despite its importance as a food security crop in Africa, its average yields and productivity are very low due to abiotic, biotic and socioeconomic constraints (Muitire, Kamutando and Moyo, 2021), making food insecurity a reality for most families, particularly small-scale farmers. In sub-Saharan Africa (SSA), smallholder farmers harvest maize on small plots of land that are often degraded and lack regular irrigation (AGRA, 2014). Climate change-related abiotic variables such as drought and heat stress have affected maize productivity more than any other crop in SSA (Masuka, Magorokosho, 2017; Serdeczny *et al.*, 2017; Kamutando, Magorokosho and Dari, 2018). Africa is considered one of the world's most vulnerable regions to climate change due to widespread poverty and insufficient coping capacity (UNFCCC, 2007; Madzwamuse, 2010). Zimbabwe is particularly vulnerable due to its heavy reliance on rain-fed agriculture and sensitive climate resources (Chaguta, 2010). According to climate statistics, Zimbabwe is already experiencing the impact of climate change, such as unpredictable rainfall and extreme weather (Brown *et al.*, 2012).

Drought has been identified as a major contributor to lower maize production and food insecurity around the world, notably in SSA, where agriculture is predominantly rain fed (Shiferaw, Prasanna and Hellin, 2011). Upwards of 90% of farmers in eastern Zimbabwe, according to (Rurinda *et al.*, 2013), believe the climate has been changing, with increasing rainfall variability defined mostly by late onset of rains and protracted mid-season dry periods. Farmers in SSA have reported 1–3 droughts within last decade, according to Fisher *et al.*, (2015), with Zimbabwean farmers experiencing the most recent droughts on average. Climate change, according to Kindie *et al.*, (2015), will cause the greatest decline in maize output in Zimbabwe, as well as several other nations in SSA, by 2050. Able to adapt towards such climate shifts is therefore vital to national food security and sustainable stability. Farmers have been focusing on implementing various methods, such as improving water accessibility and optimizing crop mix during the wet seasons (Brown *et al.*, 2012). The introduction of drought-tolerant (DT) maize cultivars has proven to be a worthwhile long-term solution. DT maize cultivars have indeed been seen as major contributor to sustaining food security, mostly under small - scale farming practices, since the late 1990s (Bänziger *et al.*, 2006)

Drought tolerant maize varieties have been developed by breeding programs and research institutions all across the globe there after (Campos, H. *et al.*, 2004). A DT maize variety has been defined by Magorokosho, Vivek and MacRobert, (2009) as a variety that can generate roughly 30% of its yield potential (1–3 t /ha) after being subjected to drought condition for at least six weeks prior to blossoming and during dry matter accumulation (grain filling). Demand for DT grains like maize and sorghum is on the rise in a number of countries, including Zimbabwe (Cavatassi, Lipper and Narloch, 2011; Fisher and Snapp, 2014; Westengen and Brysting, 2014).

Continuous research and breeding for drought-tolerant maize is becoming increasingly important in the face of climate change and more work is required. Plant breeding programs are therefore working on the development of cultivars that are well-adapted to the target environment (s). This research attempts to uncover the new genetics in freshly developed inbred lines that contribute to tolerance to stress tolerance especially drought stresses under optimal and stress environments. The findings of such research will be sufficient to advance our understanding of genetics and genotype combinations that result in new genetic combinations having significant tolerance to drought stresses.

## 1.2 Problem statement

The Crop Breeding Institute maize breeding program develops maize resilient hybrids under biotic and abiotic stress conditions prevalent in SSA. Recently, several stress tolerant hybrids were developed by crossing stress susceptible single crosses with stress tolerant donor lines within the Crop Breeding Institute maize breeding program. However, little is known on how these testcrosses (genotypes) would perform under stress environments (drought stress in particular). In addition, the stability of these testcrosses (genotypes) under stress and non-stress conditions is still unknown.

## 1.3 Justification

Exploiting the performance of the genotypes under stress conditions is very important especially when there is need for a better adapted variety on the market.  The stability analysis of these genotypes under stress and non-stress conditions will help to identify potential genotypes/hybrids that are best suited for all environments or specific environments which enable the breeders to make fully informed decisions of the materials they are working on. As a result releases of the genotypes/hybrids into the public domain will be based on the statistical information provided.

## 1.5 Aim and objectives of the study

### 1.5.1 Aim

To investigate the performance of stress tolerant maize genotypes under stress and non-stress environments

### 1.5.2 Specific objective

1. Identify hybrids/ genotypes with stable and superior yielding abilities across stress and non-stress environments
2. Identify genotypes specifically adapted to stress and non-stress environments.

## 1.6 Hypothesis

$H_o$: There are no differences in grain yield among genotypes under combined stress and non-stress environments

$H_1$: There are significant differences in grain yield among genotypes combined under stress and non-stress environments

$H_o$: Genotypes are not different in grain yield and stability under specific environments

$H_1$: There are significant differences in grain yield and stability of genotypes under specific environments

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Maize production trends in SSA

Maize is among the world's most significant and commonly produced crops (Prasanna *et al.*, 2021). Increased output in some locations, such as SSA, is connected with a huge expansion in the area under maize crop production (187 percent) not increased yields per hectare (Prasanna *et al.*, 2021). The decreased maize productivity per hectare in numerous low- and middle-income nations, compared to the world average of approximately 5 tons per hectare, could be attributable to a variety of abiotic, biotic and socioeconomic restrictions (Shiferaw, Prasanna and Hellin, 2011).

Climate variability has resulted in a 0.17 Million Metric Tonnes (MMT) per year drop in worldwide maize production over the previous three decades ((Ray *et al.*, 2019). New varieties combined with improved management practices have been shown to counteract yield reduction by up to 40% (Thornton *et al.*, 2009). Breeding for stress tolerance in the face of climate change is critical. In order to mitigate the devastating consequences of climate change, stable maize genotypes that adapt effectively to changes in climate must be bred and identified (Mendes *et al.*, 2012).

### 2.2 Factors constraining Maize production in Sub-Saharan Africa

Biotic and abiotic factors are the two major limits to world cereal output (Kosina *et al.*, 2007). Despite attempts to increase supply of food to cater to the growing demand, these are consistently lowering yield potential and crop productivity during production and after harvest (Zaidi, Rafique and Singh, 2003).

### 2.2.1 Climate induced stresses

Droughts (Hadebe, Modi, Mabhaudhi, 2017; Costa and Farrant, 2019), exceptionally high temperatures (i.e., heat stress) (Araus *et al.*, 2002), and low soil fertility are the principal abiotic factors affecting cereal production worldwide. Drought has long been viewed as one of the key reasons for the poor crop yields throughout the history of world agricultural production (Hidangmayum *et al.*, 2018)

#### 2.2.1.1 Drought

Human-caused climate change has caused drought stress, which hinders crop production and distribution globally (Aghdam et al., 2016). Climate change is expected to have the largest impact on maize output and productivity, notably in SSA, Asia and Latin America (Lobell, Schlenker and Costa-Roberts, 2011), making smallholder farmers extremely vulnerable (Lobell, Schlenker and Costa-Roberts, 2011; Cairn *et al.*, 2012). Drought constrains maize growth and output at all stages, but the reproductive stage is the most vulnerable to water deficit conditions, especially between tassel emergence and beginning grain filling (Prasanna *et al.*, 2021). Drought-vulnerable varieties can experience practically full barrenness between -2 and 22 days following anthesis, with a peak around 7 days (Prasanna *et al.*, 2021). Drought stress during this phase is commonly attributed to the separation of male and female flowering organs in the maize plant, with subsequent impacts on male–female flowering synchronization, grain setting and kernel size decrease (Bolaños and Edmeades, 1993).

#### 2.2.1.2 Heat

Generally, heat stress is sometimes described as an increase in temperature that persists for a length of time long enough to permanently harm plant growth and development. (Wahid et al., 2007) Although maize is a warm season crop, it is sensitive to high temperature stress like other cereals such as rice and sorghum (Rowhani, P. *et al.*, 2011). Heat stress is one of the major abiotic stress limiting crop productivity worldwide (Hirasawa, Ito and Hardy, 1999; Elbasyoni, I.S. *et al.*, 2018). Heat stress affect crop yield through physiological pathways different from those affected by moisture stress conditions (Wahid *et al.*, 2007). Maize is highly sensitive to temperatures greater than 35 °C during the reproductive period (Luo, 2011) and if heat stress happen during this stage, devastating results on maize production is observed. Rezaei *et al.*, (2015) mentioned that high temperatures experienced around flowering can have large negative impacts on yields due to reduced seed set and increased abortion rate

#### 2.2.1.3 Combined heat and drought

Heat stress, which is compounded by drought, is becoming a serious barrier to maize output (Cairns, Crossa *et al.*, 2013). A 2°C rise in temperature would reduce maize yields more than a 20% fall in precipitation (Lobell *et al.*, 2008). In most tropical semi-arid maize-growing locations, particularly in South and Southeast Asia, frequent spells of high temperatures (typically above 35 °C) combined with moisture stress are a common occurrence, impacting maize reproductive growth in particular (Prasanna *et al.*, 2021). Crop plants such as maize will be subjected to compounding effects of heat and drought stress unless they are irrigated often to maintain sufficient humidity to neutralize the effect of physiological drought, resulting in severe yield losses (Prasanna *et al.*, 2021)

### 2.2.2. Low soil nitrogen

In Africa, particularly SSA, poor soil fertility especially low soil nitrogen (LN) remains a widespread constraint to maize production and productivity (Das B *et al.*, 2019). Additionally, the SSA region has the lowest fertilizer application rate of about 15 kg ha$^{-1}$ compared to the global average of 140 kg ha$^{-1}$ (International Fertilizer Industry Association, 2020). Consequently, yield losses due to LN in SSA are estimated at over 50% (Amegbor , Badu-Apraku and Annor., 2017)

Suboptimal nitrogen (N) availability is a major constraint for crop production, especially in smallholder farming where chemical fertilizers are unaffordable or unavailable (Heffer and Prud'homme, 2009).

### 2.2.3 Biotic stresses

Biotic stresses, as well as abiotic variables, are wreaking havoc on cereals over the world (Kosina *et al.*, 2007) These types of stress are difficult to control because they evolve quickly and when a new strain of a pathogen emerges, for example, crop types bred to be adaptable to specific pests and diseases become susceptible to the new strain in a short period of time (Keno et *al.*, 2018) Insect pests, diseases and weeds both are biotic factors that lower crop output by causing physical harm to plant tissue, as well as physiological and biochemical impacts (Muitire, Kamutando and Moyo, 2021). Fungal, bacterial and viral infections promote diseases that are economically important in cereal production, but their importance varies by area (Muitire, Kamutando and Moyo, 2021). Turcicum leaf blight (*Exserohilum turcicum*), grey leaf spot (*Cercospora zeae-maydis*), maize streak virus disease, leaf rusts (*Puccinia sorghi*), and maize lethal necrosis (MLN) caused by a multitude of maize chlorotic mottle virus (MCMV) and ear rots, are all economically important diseases in maize (Keno *et al.*, 2018; Muitire, Kamutando and Moyo, 2021).

#### 2.2.3.1 Pest and diseases

Insect pests cause yield reductions in cereals by eating tissues for example (Fall-army worm), burrowing through stems and leaves for example (maize stalk borer), sucking plant saps (aphids), and spreading plant disease pathogens for example (white flies) (Ihtisham *et al.*, 2018). Postharvest insect pests [such as the maize weevil (*Sitophilus zeamais*) and the larger grain borer (*Prostephanus truncates*)] have been seen to cause up to 40% yield reduction globally in maize grain (López-Castillo, *et al.*, 2018). Maize stem borers (*Busiola fusca*), fall armyworm

(*Spodopetera frugiperda*) and migratory locusts (*Locusta migratoria*) (Gomaa and Bashir, 2016) are also economically significant in SSA. FAW is a relatively new insect problem in ESA, having been first documented in 2016 (Goergen, *et al.*, 2016).

### 2.3 Breeding for stress adaptation in maize

Crop enhancement for biotic and abiotic stress tolerance is thought to be the most lasting solution and less expense option for addressing present and future food supply–demand imbalances (Muitire, Kamutando and Moyo, 2021); (Costa and Farrant, 2019). Several crop insect pests and disease concerns (Gressel, 2004) as well as yield losses owing to heat and drought stress factors (Cairns *et al.*, 2013) have been handled in Africa through plant breeding. Biotic stresses are rapidly changing as a result of natural evolution and climate-related factors, rendering new crop cultivars obsolete (Muitire, Kamutando and Moyo, 2021). To generate novel varieties swiftly, modern genetic improvement procedures that include doubled haploid technology, mutation breeding and genomic selection are being exploited, especially in maize hybrid development (Prasanna *et al.*, 2021).

#### 2.3.1 Key climate resilient traits in tropical maize germplasm

Drought tolerance (DT) is among the most difficult quantitative characteristics to investigate, characterize and enhance in agricultural plants (Prasanna *et al.*, 2021). Over the last 30 years, substantial research on the genetics of water stress in maize has been conducted, particularly for traits like grain yield as well as secondary traits like anthesis-silking interval (ASI), which have a strong genetic link with grain production (Edmeades *et al.*, 2017). Reduced anthesisi silking interval (ASI) has been widely employed in traditional breeding for drought tolerance since it was discovered to be substantially linked with grain output (Bolaños and Edmeades, 1993). Several small-to-moderate effects Quantitative Trait Loci (QTL) related with grain yield were identified by Ribaut, Hoisington and Deutsch, (1996) under various levels of stress conditions; however, these QTLs were not consistent across different drought conditions (Prasanna *et al.*, 2021). Messemer *et al.*, (2009) discovered six QTLs associated with grain yield under ideal and drought conditions, with low overlap of genomic areas identified across environments, using a bigger population and higher marker frequency. Almeida *et al.,* (2013) found 83 QTLs linked to yield under drought stress, with each QTL accounting for 2.6 to 17.8% of the phenotypic variance. Seven meta-QTLs (mQTL) were found in three populations, with six of them expressed in drought and optimum conditions (Prasanna *et al.*, 2021). A meta-analysis of 18 bi-parental populations evaluated under a variety of drought and optimum conditions discovered 15 mQTLs linked to grain yield (Semagn., and Beyene, 2013). mQTLs, on the other hand, were not consistent across environments or genetic origins (Prasanna *et al.*, 2021).

In genome-wide association mapping studies (GWASs) on grain yield under drought, heat and optimal circumstances, several single nucleotide polymorphisms (SNPs) and candidate genes have been discovered across locations (Prasanna *et al.*, 2021). QTL-based marker-assisted selection is unlikely to play a substantial role in maize breeding for DT due to the lack of consistence and strong phenotypic impacts of the QTL in a variety of recipient genetic backgrounds (Prasanna *et al.*, 2021).

### 2.3.2 Application of transgenic and genome editing tools and technologies

A full understanding of the mechanisms of abiotic stress damage is required for the development of resistant plant species and variations (Lamaoui *et al.*, 2018). Crop types could benefit from transgenic-based strategies to assist them establish desired abiotic stress resistance traits. Various studies have used abiotic stress tolerance genes and transcription factors as target genes in the production of drought-tolerant plants employing biotechnological approaches (Lamaoui *et al.*, 2018). Given the advantages of commercial genetically engineered (GEn) plants (Krimsky and Schwab, 2017) and breakthroughs demonstrated with various GEn prototypes addressing abiotic stresses in crops, widespread adoption of GEn remains a major challenge due to widespread public opposition to the intentional introduction of genes into plants, especially in crops (Krimsky and Schwab, 2017). The widespread deployment of this approach, particularly in Europe, remains a major difficulty due to the negative public perception of the purposeful insertion of genes into plants (Krimsky and Schwab, 2017).

### 2.4 Agronomic strategies for improving tolerance to biotic and abiotic stress

Crop management practices can potentially alleviate the harmful effects of drought stress in the soil. Crop rotation, good fertilizer regime, seeding time, cultivation procedures, appropriate cultivar selection, appropriate seed rate, effective weed suppression management, careful soil nutrient management and adequate water availability, have all been shown to reduce both abiotic and biotic stresses in grain production (Hidangmayum *et al.*, 2018). Maize damage from FAW was greatly decreased in Zimbabwean small-scale farming by repeated weeding and minimal tillage (Baudron, F. *et al.*, 2019). Because weeds face competition with crops for accessible moisture, effective weed control lessens moisture stress in cereal production (Ihtisham *et al.*, 2018). Micronutrients such as B, Se and Mn, as well as macronutrients like K and Ca, are thought to affect stomatal activity under heat stress according to Waraich *et al.*, (2012), thereby assisting in the activation of physiological and metabolic processes that contribute to the maintenance of a high water potential in tissues, improving heat stress tolerance (Waraich *et al.*, 2012). The use of minerals such as N, K, Ca and Mg has also been shown to increase the antioxidant enzyme concentration in plant cells, lowering Reactive Oxygen Species (ROS) toxicity (Waraich *et al.*, 2012).

### 2.5 Prediction of stable genotypes

Adaptability and stability studies illustrate how genotypes behave differently in different conditions. Producing genotypes that are high yielding and retain their performance across diverse conditions is one of the major breeding programs aims in maize projects (Mendes *et al.*, 2012). Stability is described as a genotype's ability to maintain stable yields despite the environmental factors, which is significant since genotype x environment interaction (GEI) influences how varieties perform in different environments (Mendes *et al.*, 2012). This necessitates a detailed examination of the performance of various locations. Genotype-genotype x environment (GGE) bi-plots, the most often used method, is one tool that can help with the stability assessment (Kamutando *et al.*, 2013; Holland, 2014). In completing the research that shows genotype stability under multiple contexts, additive main effect and multiplicative interaction (AMMI) (Yan and Tnker, 2006) is equally relevant.

# CHAPTER 3

## 3.0 MATERIALS AND METHOIDS

### 3.1 Site description

Site description is shown in table 3.1

### 3.2 Experimental design

The 22 experimental hybrids/testcrosses/genotypes and eight check varieties were planted at each of the 4 sites using an alpha (0.1) lattice design with three replications. Each replication had 3 incomplete blocks with a block size of ten entries.

**Table 3. 1 Evaluation sites used during the study representing different maize growing conditions**

| Site | Chiredzi | CBI Harare | Gwebi | Chisumbanje |
|---|---|---|---|---|
| **Latitude** | 21$^{0}$1`10``S | 17$^{0}$49`S | 17$^{0}$40`41`S` | 20° 48' 0S |
| **Longitude** | 31$^{0}$34`23``E | 31$^{0}$01`E | 30051`49``E | 32°13'60"E |
| **Type of irrigation** | Overhead sprinkler | Overhead sprinkler | Overhead sprinkler | Flood |
| **Rainfall received** | <450mm | 750-1000mm | 750-1000mm | <450mm |
| **Altitude (m.a.s)** | 445 | 1480 | 1438 | 412 |
| **Natural Region** | IV | IIa | IIa | IV |
| **Soil type** | Triangle e-series | Clay | MG/SCL | Basalt Clays |
| **Management** | Managed Drought | Optimal | Optimal | Managed Drought |

### 3.3 Trial establishment and site management

The entries were hand planted at all sites in two row plots of 4m long each and 0.75cm spacing between rows and 0.25 between hills in 2021-22 summer season and winter. Two seeds per planting station were used at planting and thinned three weeks after emergence to obtain a final plant population of 53 333 plants per ha. Basal fertilizer (Compound D) was applied at a rate of 400kg per ha and top dressing (Ammonium nitrate) at a rate of 400 kg per ha. Well-watered trials were planted under rain fed conditions and, managed drought stress trials were planted in late winter under irrigation (withholding irrigation three weeks before the expected date of flowering to induce drought).

### 3.4 Data collection

Data was recorded as described in Table 3.2.

**Table 3. 2 Data collection**

| | |
|---|---|
| Days to anthesis (AD) | Taken as number of days from planting to when 50% of the plants in a plot were shedding pollen and had emerged silk of at least 5cm |
| Days to silking (SD) | Taken as number of days from planting to when 50% of the plants in a plot had emerged silk of at least 5cm |
| Anthesis to silking interval (ASI) | Difference between days to silking and anthesis |
| Plant(PH) | Recorded on five randomly selected plants as distance from the ground to the base of tassel |
| Ear heights (EH) | Recorded on five randomly selected plants as distance from the ground to upper ear respectively |
| Number of ears per plant (EPP) | Computed as the proportion of the total number of ears harvested divided by total number of plants harvested |
| Ear Aspect (EA) | Scored on a scale of 1-5, where 1-clean, uniform, large and well filled ears and 5-rotten, variable, small, and partially filled ears |
| Grain yield (GYD) | Computed from shelled grain weight per plot using a scale and adjusted to 12.5% grain moisture using field-book software |

### 3.5 Data Analysis

Analysis of Variance (ANOVA) conducted using GenStat 18th Edition. Fischer protected LSD in Genstat 18th Edition was used to separate the means where there were significant differences Grain yield stability analysis, the “genotype + genotype × environment” (GGE) biplots shall be drawn following the procedures in Payne et al. (2009) using the GenStat Software 18th Edition.

**Table 3. 3 Skeletal ANOVA**

| **Source of variation** | **Degrees of Freedom** | **Sum of Squares** | **Mean squares** | F |
|---|---|---|---|---|
| Replications | r-1 | $SS_r$ | $MS_r$ | |
| Blocks(within replications) | rs-r | $SS_b$ | $MS_b$ | |
| Treatments | t-1 | $SS_t$ | $MS_t$ | $F_0$ |
| Error | rt-rs-t+1 | $SS_e$ | $MS_e$ | |
| Total | tr-1 | $SS_T$ | | |

# CHAPTER 4

## 4.0 RESULTS

### 4.1 Yield performance of candidate hybrids (genotype) across optimum and managed drought environments

Results of the analysis of variance combined across environments revealed that entry mean squares were significant for grain yield across all environments. Components of interaction effects were also significant. (Table 4.1). Candidate testcrosses (genotypes) 143WH705 and 143WH742 consistently showed best grain yield performance outcompeting all check varieties across optimum and managed drought environments. Testcross 143WH728 was comparable to checks under optimum and across environments, however, it was outcompeted by checks under managed drought conditions (Table 4.2)

**Table 4. 1 Analysis of Variance (ANOVA) for grain yield across four environments, two optimum and two managed drought environments in 2021/22**

| Source | d.f. | s.s. | m.s. | v.r. | F pr. |
|---|---:|---:|---:|---:|---:|
| Environment | 3 | 2575.7603 | 858.5868 | 1441.81 | <.001 |
| Environ. REP | 8 | 7.3746 | 0.9218 | 1.55 | 0.142 |
| Environ. REP.BLK | 24 | 74.2331 | 3.0930 | 5.19 | <.001 |
| Genotype | 29 | 440.0125 | 15.1728 | 25.48 | <.001 |
| Environ. Genotype | 87 | 307.8455 | 3.5385 | 5.94 | <.001 |
| Residual | 208 | 123.8620 | 0.5955 | | |
| | | | | | |
| Total | 359 | 3529.0879 | 9.8303 | | |

**Table 4. 2 Mean grain yield (t ha$^{-1}$) of candidate testcrosses (genotypes) relative to check varieties in preliminary variety trials under optimum, managed drought and across environments in 2021/22**

| Variety | Harare Opt Environ | Gwebi Opt Environ | Across Opt Environ | Chiredzi Mgt Drought Environ | Chisumbanje Mgt Drought Environ | Across Mgt Drought Environ | Across all Environ |
|---|---|---|---|---|---|---|---|
| SC719 | [Σ]12.421a | 12.541a | 12.48a | 1.88efghijk | 2.72cdef | 2.30efghij | 7.39b |
| 143WH705 | 11.866ab | 12.098a | 11.98ab | 4.21ab | 4.61a | 4.41ab | 8.20a |
| 143WH742 | 11.752ab | 12.063a | 11.91ab | 4.71a | 4.79a | 4.75a | 8.33a |
| PAN7M-81 | 10.705b | 9.91bc | 10.31c | 2.09defghijk | 2.812bcdef | 2.45defghij | 6.51c |
| 143WH728 | 10.558b | 11.462ab | 11.01bc | 1.30ijk | 2.73cdef | 2.014ij | 6.51c |
| PHB30G19 | 10.480b | 9.63cd | 10.10c | 1.465hijkl | 3.18bcd | 2.32efghij | 6.19cd |
| PAN53 | 8.829c | 8.03efg | 8.48def | 3.14bcde | 2.78bcdef | 2.96de | 5.72de |
| MUKWA | 8.183cd | 8.90cde | 8.54de | 3.19bcd | 2.76bcdef | 2.98de | 5.76de |
| ZS265 | 8087cd | 9.20cde | 8.64d | 3.08bcdef | 4.41a | 3.74bc | 6.19cd |
| ZAP63 | 7.803cde | 8.41cdefg | 8.11defg | 2.351cdefghij | 3.25bc | 2.80defg | 5.46ef |
| SC555 | 7.354defg | 8.50cdefg | 7.93defgh | 2.70cdefgh | 2.86bcdef | 2.78defg | 5.53efg |
| PAN413 | 7.121defgh | 7.04hijk | 7.08ghi | 1.74ghijkl | 2.61ef | 2.174dhij | 4.63hij |
| SC403 | 7064defgh | 7.70efgh | 7.38gh | 1.8fghijkl | 2.9bcdef | 2.35efghij | 8.87fghij |
| Mean | 7.65 | 8.22 | 7.94 | 2.32 | 3.12 | 2.72 | 5.33 |
| LSD (0.05) | 1.411 | 0.7733 | 1.036 | 1.299 | 0.5536 | 0.6979 | 0.6211 |
| CV | 10.99 | 11.53 | 11.28 | 33.77 | 11.02 | 22.51 | 14.38 |
| P | *** | *** | *** | *** | *** | ** | *** |

[Σ] For each column, means with the same letter are not significantly different according to Fischer's protected LSD (0.05). *** Significant at P ≤ 0.001; ** Significant at P ≤ 0.01

## 4.2 Stable and highly productive candidate genotypes cross optimum and managed drought environments

Genotypes 143WH705, 143WH742 and were high yielding and stable across optimum and managed drought conditions. These genotypes outperformed the checks both in-terms of grain yield and grain yield stability since they are located in the inner concentric ring and away from the origin (Figure 4.1)

## 4.3 Agronomic secondary traits across stress and non-stress environments

The ANOVA table 4.3 shows significant differences in PH, ASI and PH: EH among genotypes. Highly heritable traits (PH and Flowering) were computed only on single site. Table 4.4 shows agronomic performance of candidate genotypes/ hybrids. AD ranges from 66 days to 70 days with candidate hybrids ranging from 67.33-68.67, ASI interval has a range from 1.917 days to 3.417 days. Also plant height ranges from 207.7cm up-to 2.83.7 cm with candidate hybrids averaging around 245cm. The ratio between plant height and ear height had a minimum of 0.4412% and a maximum 0.5772%. The hybrids under study had a range between 0.4871 and 0.5277%

## Table 4.3 ANOVA table for Agronomic secondary traits across stress and non-stress environment

| | **Optimum environment** | | | | **Across environments** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | PH | | AD (days) | | | ASI | | PH:EH | |
| **Source** | df | P-Value | df | P-Value | Source | df | P-Value | df | P-Value |
| REP | 2 | 0.02 | 2 | 0.955 | REP | 2 | 0.096 | 2 | 0.122 |
| REP.BLK | 6 | 0.205 | 6 | 0.86 | REP.BLK | 6 | 0.344 | 6 | 0.095 |
| Genotype | 29 | <0.001 | 29 | 0.345 | Genotype | 3 | 0.01 | 3 | <0.001 |
| Residual | 52 | | 52 | | Environ | 29 | 0.418 | 29 | >0.001 |
| Total | 89 | | 89 | | Environ. Genotype | 87 | 0.432 | 87 | 0.038 |
| | | | | | Residual | 232 | | 232 | |
| | | | | | Total | 359 | | 359 | |

AD= days to anthesis; ASI= anthesis silking interval, PH= plant height; PH: EH= ratio of ear height to plant height as a percent

**Table 4.4. Agronomic secondary traits across stress and non-stress environments**

| Name | AD (days) | ASI (days) | PH (cm) | PH: EH (%) |
|---|---|---|---|---|
| SC719 | 70 | 2.833abc | 283.7a | 0.5772ab |
| 143WH705 | 67.33 | 2.833abc | 243.7defg | 0.5277abcedefg |
| 143WH742 | 67.67 | 1.917c | 249cdef | 0.4871fghi |
| PAN7M-81 | 67.33 | 1.917c | 260.7abcde | 0.5610abc |
| 143WH728 | 68.67 | 3.000ab | 250.3bcdef | 0.498defghi |
| PHB30G19 | 67.33 | 3.000ab | 273.7ab | 0.484ghi |
| PAN53 | 68.67 | 2.750abc | 257bcdef | 0.4953defghi |
| MUKWA | 66.67 | 2.583abc | 233.3fg | 0.5242abcdefg |
| ZS265 | 66.60 | 2.417abc | 250.3bcdef | 0.5815a |
| ZAP63 | 67.67 | 2.833abc | 259.7abcde | 0.4997cdefghi |
| SC555 | 67.33 | 2.167bc | 261abcde | 0.4559i |
| PAN413 | 67.67 | 3.417a | 207.7gh | 0.4881fghi |
| SC403 | 66.51 | 2.333bc | 242.3efg | 0.4412j |
| Lsd | 3.496 | 1.006 | 24.6 | 0.06154 |
| P-value |  | ** | *** | *** |

AD= days to anthesis; ASI= anthesis silking interval, PH= plant height; PH: EH= ratio of ear height to plant height as a percent

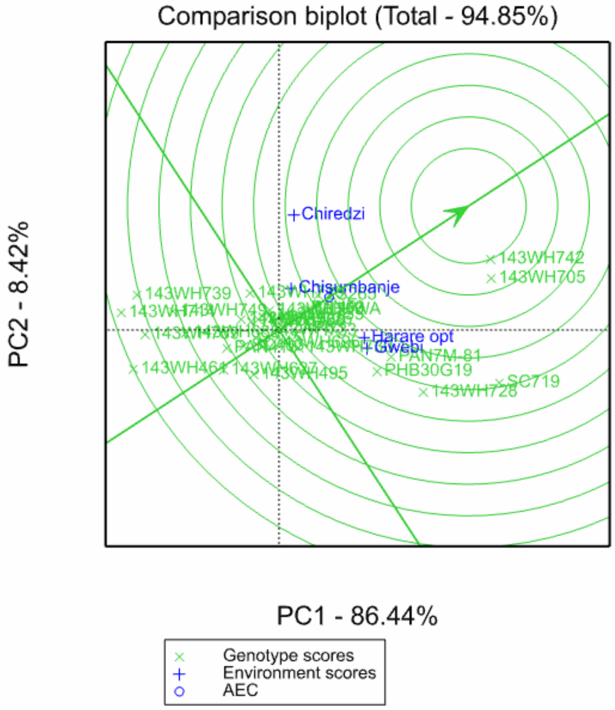

**Figure 4. 1 GGE comparison biplot based on genotype-focused scaling for comparing the stability of genotypes with the ideal genotype across environments (optimum and managed drought) in 2021/22season**

## 4.4 Stable and highly productive candidate genotypes under optimum environments

Genotypes 143WH705, 143WH742 and 143WH728 were high yielding and stable across all optimum environments. These genotypes outperformed the checks except for SC 727 both in-terms of yielding abilities and grain yield stability (Figure 4.2)

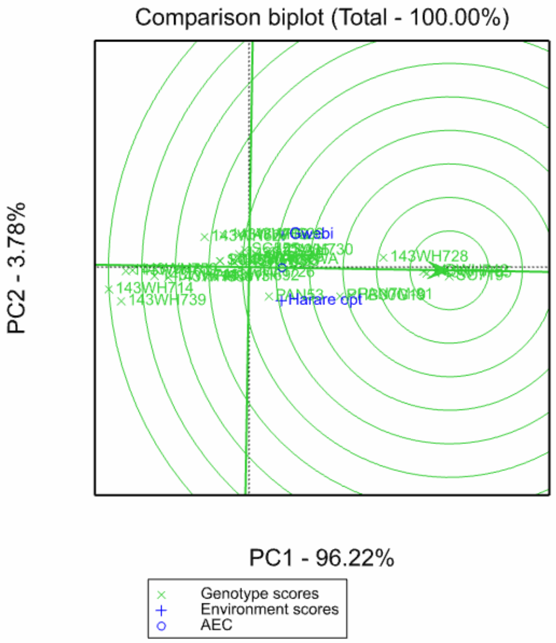

**Figure 4. 2: GGE comparison bi-plot based on genotype-focused scaling for comparing the stability of genotypes with the ideal genotype under optimum environments in 2021/22 season**

## 4.5 Stable and highly productive candidate hybrids under managed drought stress environments

Genotypes 143WH705, 143WH742 consistently showed high yielding abilities and stability traits across all managed drought stress environments. These genotypes outperformed all the check varieties. However, genotype 143WH728 was not stable and was low yielding under drought stress environments

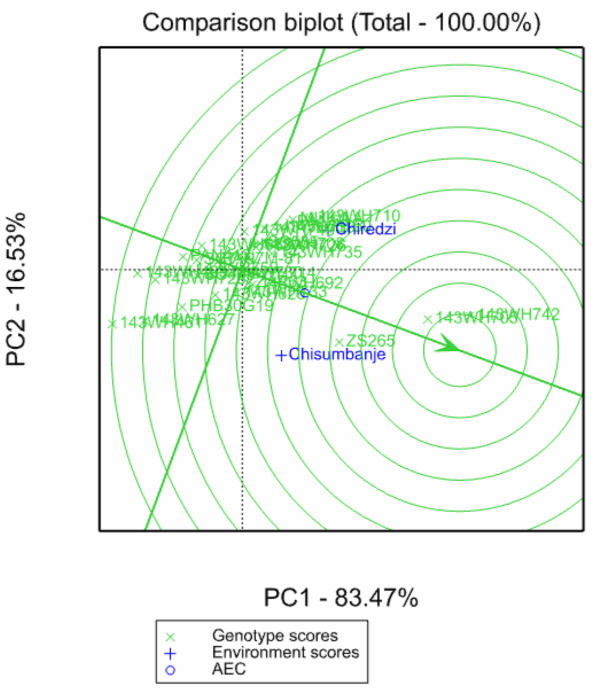

**Figure 4. 3 GGE comparison biplot based on genotype-focused scaling for comparing the stability of genotypes with the ideal genotype under managed drought environments in 2021/22 season**

# CHAPTER 5

## 5.0 DISCUSSION.

The results of an ANOVA indicated significant variations in grain yield among genotypes in different environments. A GGE comparison bi-plot based on genotype-focused scaling for comparing the stability of genotypes with the ideal genotype showed that genotypes 143WH705 and 143WH742 were exceptional in terms of high grain yielding and stability when compared to the checks under optimum and stressed environments. These findings are in line with the focus of the breeding institute, which aims to develop maize genotypes with superior genetics.

Yield is the key trait in maize breeding and selection of superior genotypes is basically biased on yield. The genotypes under study (143WH728, 143WH705, and 143WH742) showed better gains in terms of genetics since they performed above the experimental mean and also have high genetic potential in terms of grain yield, which is above 10 t/ha under non-stress environments. Genotypes 143WH705 and 143WH742 have genes that are more tolerable to drought environments since they not only performed above all checks but also had a grain yield of around 4t/ha under drought stress environments. Having yields of 4 t/ha under stressed environments is a great achievement since most of the material in the experiment staggered around 2t/ha.

In addition to high grain yields, candidate genotypes (143WH728, 143WH705, and 143WH742) showed good agronomic traits. Early maturity and average plant height of 250cm exhibited by hybrids answers the call by farmers in the face of climate change since more than 60% of the land under maize production is contributed by marginalized communal farmers (Crop, Livestock and Fisheries Assessment Report, 2023) who require early maturing short statured maize plants. Anthesis silking interval ranging between 1.917 and 3 together with PH: EH averaging around 50% exhibited by the candidate hybrids (143WH728, 143WH705, and 143WH742) are recommendable ASI and ear position respectively. In maize production ASI (split) of <-5 and >5 is regarded as very poor and the hybrid of such has very low percentage of seed reproducibility. Also PH: EH of 50% and below is recommended in maize hybrids.

# CHAPTER 6

## 6.0 CONCLUSIONS AND RECOMMENDATIONS

### 6.1 Conclusions

Overall, the results of this study suggest that genotypes 143WH705 and 143WH742 and 143WH728 are promising candidates for further development and commercialization. These genotypes have superior genetics, good agronomic traits, and are tolerant to drought stress. They have the potential to improve maize yields and help farmers adapt to climate change.

### 6.2 Recommendations

The results depicted by the study are preliminary yield trials. It is in the best interest of the breeder to select materials suitable for the breeding work and advance it to the advanced trials for further testing. Testcrosses/hybrids 143WH705 and 143WH742 and 143WH728 can be further subjected to multiple stress conditions to ascertain there performance. The hybrids can as well be evaluated in environment-specific conditions to see if they can outperform checks particularly bred for such conditions. If the results are consistent, hybrids 143WH705 and 143WH742 can be recommended for release for stressed and non-stressed environments and testcross 143WH728 be recommended specifically for non-stressed environment

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# APPENDICES

## Appendix1. Across site (non-stressed environment) mean grain yield

| Hybrid | Mean grain yield (t/ha) |
|---|---|
| SC719 | 12.481 |
| 143WH705 | 11.982 |
| 143WH742 | 11.908 |
| 143WH728 | 11.01 |
| PAN7M-81 | 10.309 |
| PHB30G19 | 10.057 |
| ZS265 | 8.642 |
| MUKWA | 8.541 |
| PAN53 | 8.478 |
| 143WH730 | 8.451 |
| ZAP63 | 8.109 |
| SC555 | 7.928 |
| 143WH735 | 7.804 |
| 143WH750 | 7.799 |
| 143WH626 | 7.785 |
| 143WH733 | 7.7 |
| 143WH495 | 7.659 |
| 143WH726 | 7.602 |
| 143WH708 | 7.448 |
| SC403 | 7.383 |
| 143WH710 | 7.371 |
| 143WH692 | 7.259 |
| PAN413 | 7.078 |
| 143WH627 | 7.025 |
| 143WH688 | 6.233 |
| 143WH749 | 5.929 |
| 143WH759 | 5.435 |
| 143WH461 | 5.287 |
| 143WH739 | 5.196 |
| 143WH714 | 4.916 |

**Appendix 2. Across site (stressed environment) mean grain yield**

| Hybrid | Mean grain yield (t/ha) |
|---|---:|
| 143WH742 | 4.751 |
| 143WH705 | 4.411 |
| ZS265 | 3.744 |
| 143WH710 | 3.112 |
| MUKWA | 2.976 |
| PAN53 | 2.959 |
| 143WH735 | 2.905 |
| 143WH750 | 2.903 |
| 143WH692 | 2.842 |
| ZAP63 | 2.803 |
| SC555 | 2.778 |
| 143WH739 | 2.768 |
| 143WH726 | 2.751 |
| 143WH733 | 2.735 |
| 143WH708 | 2.73 |
| 143WH749 | 2.607 |
| 143WH714 | 2.583 |
| 143WH626 | 2.561 |
| 143WH730 | 2.471 |
| PAN7M-81 | 2.451 |
| SC403 | 2.35 |
| PHB30G19 | 2.323 |
| SC719 | 2.298 |
| 143WH688 | 2.296 |
| 143WH759 | 2.255 |
| PAN413 | 2.174 |
| 143WH627 | 2.054 |
| 143WH728 | 2.014 |
| 143WH495 | 1.845 |
| 143WH461 | 1.792 |

## Appendix 3. Across site (stressed and non-stressed environment) mean grain yield

| Hybrid | Mean grain yield (t/ha) |
|---|---|
| 143WH742 | 8.329 |
| 143WH705 | 8.196 |
| SC719 | 7.39 |
| 143WH728 | 6.512 |
| PAN7M-81 | 6.38 |
| ZS265 | 6.193 |
| PHB30G19 | 6.19 |
| MUKWA | 5.758 |
| PAN53 | 5.719 |
| 143WH730 | 5.461 |
| ZAP63 | 5.456 |
| 143WH735 | 5.354 |
| SC555 | 5.353 |
| 143WH750 | 5.351 |
| 143WH710 | 5.242 |
| 143WH733 | 5.217 |
| 143WH726 | 5.177 |
| 143WH626 | 5.173 |
| 143WH708 | 5.089 |
| 143WH692 | 5.05 |
| SC403 | 4.867 |
| 143WH495 | 4.752 |
| PAN413 | 4.626 |
| 143WH627 | 4.54 |
| 143WH749 | 4.268 |
| 143WH688 | 4.264 |
| 143WH739 | 3.982 |
| 143WH759 | 3.845 |
| 143WH714 | 3.75 |
| 143WH461 | 3.54 |

## Appendix 4. Mean plant height

| Genotype | Plant Height |
|---|---|
| 143WH749 | 70.33 |
| 143WH710 | 70 |
| 143WH735 | 70 |
| 143WH692 | 69.67 |
| SC403 | 69.33 |
| 143WH726 | 69.33 |
| 143WH495 | 68.67 |
| PAN53 | 68.67 |
| 143WH626 | 68.67 |
| 143WH728 | 68.67 |
| 143WH733 | 68.67 |
| SC719 | 68.67 |
| 143WH461 | 68.33 |
| 143WH750 | 68.33 |
| 143WH730 | 67.67 |
| 143WH742 | 67.67 |
| PAN413 | 67.67 |
| ZAP63 | 67.67 |
| 143WH627 | 67.67 |
| 143WH688 | 67.67 |
| 143WH708 | 67.67 |
| SC555 | 67.33 |
| 143WH739 | 67.33 |
| 143WH705 | 67.33 |
| PAN7M-81 | 67.33 |
| PHB30G19 | 67.33 |
| MUKWA | 66.67 |
| ZS265 | 66 |
| 143WH759 | 65.33 |
| 143WH714 | 65 |

**Appendix 5. Across environments Plant height: Ear height**

| Genotype | PH:EH |
|---|---|
| ZS265 | 0.5815 |
| SC719 | 0.5772 |
| PAN7M-81 | 0.561 |
| 143WH749 | 0.5555 |
| 143WH692 | 0.553 |
| 143WH739 | 0.5508 |
| 143WH759 | 0.5473 |
| 143WH730 | 0.5417 |
| 143WH626 | 0.5401 |
| 143WH750 | 0.5374 |
| 143WH710 | 0.5358 |
| 143WH708 | 0.5344 |
| 143WH733 | 0.5313 |
| 143WH735 | 0.5291 |
| 143WH705 | 0.5277 |
| MUKWA | 0.5259 |
| 143WH688 | 0.5242 |
| 143WH627 | 0.5233 |
| 143WH726 | 0.5209 |
| 143WH495 | 0.5198 |
| ZAP63 | 0.4997 |
| 143WH728 | 0.498 |
| PAN53 | 0.4953 |
| 143WH714 | 0.4913 |
| PAN413 | 0.4881 |
| 143WH742 | 0.4871 |
| PHB30G19 | 0.484 |
| 143WH461 | 0.4587 |
| SC555 | 0.4559 |
| SC403 | 0.3779 |