EVALUATION OF YELLOW MAIZE (*Zea mays L*) INBRED LINES' PERFORMANCE AND COMBINING ABILITY USING LINE BY TESTER ANALYSIS IN WESTERN KENYA

DANIEL WAMACHE SHIUNDU

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DECLARATION

Declaration by the Candidate

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SHIUNDU Daniel Wamache

________________________________ Date________________________

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Approval by the Supervisors

This thesis has been submitted with our approval as the university supervisors.

________________________________ Date________________________

Dr. Kennedy Pkania
University of Eldoret, Kenya

________________________________ Date________________________

Dr. Emmy Chepkoech,
University of Eldoret, Kenya

DEDICATION

This thesis is dedicated to my late father (Mr. John Mukhwenda Shiundu) and my mother Mrs. Felistus Shiundu who instilled in us the passion to study at our tender ages as their children.

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ABSTRACT

There is need to continuously develop and deploy highly adaptable and productive maize hybrid varieties for use by farmers against the greatly dynamic biotic and abiotic stresses that face production of this crop in the country. The objective of this study was to estimate the hybrid performance and the combining abilities of yellow maize inbred lines and their testcrosses for grain yield and yield-related traits across three locations. Sixty-five yellow maize inbred lines were crossed to two-line testers; Cimmyt maize lines (CML) 486 (Tester A) and 451 (Tester B) using a line by tester design. Resultant a hundred and thirty F_1 testcrosses with three check varieties were evaluated on three locations in western Kenya using a 7×19 alpha lattice with two replications. Data on grain yield and yield-related traits was collected. Means and variance components on hybrid performance were computed in META-R version VI and combining ability analysis done using Restricted maximum likelihood (REML). Grain yield means ranged between 12.4T/Ha and 2.8T/Ha with testcross L45×TA producing the highest grain yield mean across sites. High heritability (>60%) was recorded for grain yield and other yield-related traits except for northern leaf blight which was moderate. All yield-related traits in the study except northern leaf blight had significant phenotypic correlations with grain yield. Ear height had the highest positive correlation at 0.7($P<0.001$). Across sites Analysis of Variance (ANOVA) revealed highly significant ($p<0.001$) mean squares for sites, hybrids, line general combining ability (GCA) line GCA by site, hybrid by site, specific combining ability (SCA) as well as SCA by site. L45 had the highest positive GCA for grain yield at 2.7 ($p<0.05$). L23, L65, L29 and L25 crossed with tester A showed positive significant SCA estimates for grain yield whereas L36×TA had a negative but significant SCA for grain yield at -1.9 ($p<0.05$). Based on SCA estimates with the testers, the inbred lines grouped into two heterotic groups A and B with 60% and 38.5% of the inbred lines respectively. L45 and other 33 lines that had positive GCA for grain yield could be exploited in the development of high yielding yellow maize hybrids. Testcrosses L45xTA, L47xTA and L35xTB showing equivalent or better performance to the mean of the checks have potential for further evaluation and consideration for release as adaptable and stable superior yielding yellow maize single cross hybrids.

Key words: Maize, hybrid performance, combining ability, heterotic grouping.

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LIST OF ABBREVIATIONS

AD	Anthesis date
AGD-R	Analysis of Genetic designs in R.
AMMI	additive main effects multiplicative interactions
ASED	average standard error of the difference
BIBD	balance incomplete block design
BLUEs	Best linear unbiased expectations
CAN	Calcium ammonium nitrate
CIMMYT	International Centre for Wheat and Maize improvement
CML	CIMMYT line
CV	Coefficient of variation
DAP	Di-ammonium phosphate
EH	ear height
FAO	Food and Agriculture Organisation
GCA	General combining ability
G×E	Genotype by environment
GLS	Grey leaf spot
GY	grain yield
H^2	broad sense heritability
h^2	narrow sense heritability
LSD	Least significant difference
L×T	Line by tester.
MET	Multi environment trial
META-R	Multi-environment Trial analysis in R
NLB	Northern leaf blight

NPT	National performance trials
PH	plant height
REML	Restricted maximum likelihood
SCA	Specific combining ability
T/Ha	tonnes per hectare
TEX	Texture
WAP	weeks after planting

CHAPTER ONE

INTRODUCTION

1.1 General background

In the sub-Saharan Africa (SSA) region, maize (*Zea mays* L.); is a significant cereal crop as it forms an important component of the food, feed, and fodder systems contributing up to 80% to the income generation of many rural households (Prasanna et al., 2020). It is considered the main staple food for the Kenyan population, thus providing more than one-third of the caloric intake (Mang'eni, 2022). In agricultural production, maize accounts for 56% of cultivated land in Kenya (Mang'eni, 2022).

Yellow maize is becoming a critical component in the cereal requirements of Kenya and the region at large (VIB, 2017). This has been necessitated by the increasing awareness of the nutritional advantage over white maize as a component in animal feeds and fodder. Towards the end of the physical year 2022, the Ministry of Agriculture in Kenya gave a green light to animal feed manufacturers for the importation of 350,000 tonnes of yellow maize duty-free for a period of one year in an effort to address high maize prices (Business Daily Africa, Dec 2022). This move was aimed at easing pressure on white maize, which is heavily utilized as food. Feed manufacturers have been proposed to support a contract farming system for the local production of raw materials, including yellow maize, to be used for feed production to lower the cost of feeds and cut expensive imports (Business Daily Africa, Dec. 2022).

Yellow maize contains many essential vitamins, with pro-vitamin A carotenoids and vitamin E as the predominant fat-soluble vitamins in their kernels (Nuss & Tanumihardjo, 2010). However, white maize is the predominant food maize in Africa, and pro-vitamin A carotenoids are absent in its kernels (Mangelsdorf & Bramley, 2004). As a result, populations without access to a diversified diet, in general, chronically suffer from vitamin A deficiency. A prolonged lack of vitamin A is the primary cause of childhood blindness and significantly raises the risk of illness and death from serious infections (VIB, 2016). In pregnant women, a deficiency in vitamin A can lead to night blindness and heighten the risk of maternal death. Additionally, carotenoids have a protective function in reducing the risk of cancer, cardiovascular diseases, and other chronic diseases (Fraser & Bramley, 2004)

There exists considerable disparity on yellow maize in Kenya that has tremendously limited its production and consumption unlike in developed countries where it is the most preferred with up-to 70 % utilization as animal feed (Aguk et al., 2021). Despite the tremendous nutritional and health values associated with yellow maize, there is still a need for a robust public awareness campaign in Kenya to increase consumer knowledge and, hence, adoption.

Maize production in Kenya faces challenges similar to those experienced in other production ecologies in SSA. A reduction in arable land mass due to increasing populations is a major constraint, in addition to other biotic and abiotic factors such as low nitrogen, salinity, emerging diseases, and pests. With this in mind, breeding for highly productive and adaptable maize varieties has become a major preoccupation of maize breeders in SSA.

1.2 Statement of the problem

Maize (*Zea mays*) is a vital staple crop that supports global food security and sustains the livelihoods of millions, particularly in sub-Saharan Africa (SSA) and various other regions worldwide (FAOSTAT, 2024). However, limited maize production has become a significant challenge in many regions due to multiple factors, including climatic changes, soil degradation, inadequate agricultural practices and insufficient access to modern farming technologies. Maize farmers have inadequate access to information, limited financial capacities, and insufficient technical support (Ntshangase et al., 2018). The increasing occurrence of droughts, unpredictable rainfall patterns and increasing temperatures exacerbated by climate change, have led to reduced yields and have severely affected maize farming in many regions (Gebrechorkos et al., 2019; Nhemachena et al.,2020; Niang et al., 2021)

Numerous breeding programs in both the public and private sectors in Kenya and in SSA have embraced development of new maize hybrid varieties and have shown promise in improving productivity and adaptation to both biotic and abiotic stresses. Just like in white maize breeding programs, the success of yellow maize breeding programs has been constrained by the limited genetic diversity within maize breeding germplasm (Tian et al., 2018; Smith et al., 2022). The narrowing of genetic diversity, particularly in elite yellow maize lines, has been a critical issue due to the overreliance on limited sets of germplasm for breeding purposes, which restricts the ability to address emerging challenges such as pest resistance, drought tolerance, and changing climate conditions (Melchinger et al., 2017). Just like in many regions, maize breeders in SSA struggle to find genetically diverse and climate-resilient germplasm, which hinders the progress of breeding efforts aimed at improving productivity and sustainability (Prassana et al., 2021). This necessitates finding of sources of variability including using introductions as well as use of advanced genomic tools and innovative breeding techniques that can facilitate the identification and integration of beneficial traits from diverse germplasm into elite maize lines (Burgueño et al., 2021).

Lack of information on the performance potential, combining ability of newly developed or introduced breeding yellow maize inbred lines as well as their heterotic grouping can be a serious impediment in achieving the objective of creating superior yellow maize hybrids using an introduced germplasm.

This study thus sort to evaluate hybrid performance potential of an introduced pool of lines, their combining ability as well their heterotic grouping.

1.3 Justification.

In Kenya, maize is a major staple whose production has stagnated over time to below 2 (t/ha) on average for the past ten years (FAOSTAT, 2024) despite the increasing population size that is projected to reach 53 million by 2030 as reported by KNBS (2019). This production is affected by a huge array both biotic and abiotic stresses including changing climatic conditions, pests and diseases. There is thus need to continuously develop and deploy superior yielding and stress tolerant hybrids which are adaptable to varying production systems to meet the ever-increasing demand of this commodity as a source of food, feed and fodder in both white maize and yellow maize.

Yellow maize hybrid development becomes of great significance as this is seen to have the potential to alleviate the overdependence on white maize in SSA. Thus, development of these superior and adaptable new yellow maize hybrids requires exploitation of diverse germplasm sources using different mating schemes, which can provide breeders with optimum information for selection and deployment of new varieties.

Kempthorne first proposed the Line by Tester analysis in 1957, as cited by Sharma (2006). This analysis has proven to be a reliably good tool for determining both the GCA of inbred lines and the SCA of their crosses, especially when the number of entries involved is large.

This design which involves crossing between lines (X) and testers (Y) in one to one fashion generating X × Y = XY hybrids (Sharma, 2006) is the simplest mating design that provides both full-sibs and half-sibs simultaneously as opposed to top cross which provides only half-sibs. It provides SCA of each cross, and it does not provide GCA of lines only but of the testers also, as line and tester both are different sets of genotypes (Sharma, 2006). The analysis shows that lines with positive and significant GCA for grain yield could be used in hybridization programs to develop high-yielding yellow maize hybrids for the target ecologies. Researchers could also use these lines to develop single cross source parents for creating new lines with potentially good GCA using Double Haploid (DH) technology.

This study sought to provide breeders with valuable insights into the genetic potential of the parental lines, enabling more precise and effective hybrid development. This, in turn, will contribute to the production of high-yielding, robust hybrids that can meet future agricultural demands.

1.4. Study objectives

1.4.1 General objective

To estimate the yellow maize test cross performance and the combining abilities of the inbred lines and their test crosses for grain yield and yield-related traits.

1.4.2 Specific objectives

1. To evaluate the performance, heritability and phenotypic correlations of grain yield and yield-related traits of yellow maize inbred lines.
2. To estimate the GCA and SCA of resultant F_1 test crosses of yellow maize inbred lines for grain yield and yield-related traits.
3. To determine the heterotic grouping of the yellow maize inbred lines based on the SCA estimates of their test crosses for grain yield.

1.4.3 Null hypotheses

i. There is no significant difference in the mean test cross performance, heritability and phenotypic correlations of traits of the yellow maize inbred lines in hybrid combinations.

ii. Variance components for GCA and SCA for grain yield and yield-related traits do not differ significantly.

iii. Inbred lines in the study did not show significant difference in their heterotic orientation.

CHAPTER TWO

LITERATURE REVIEW

2.1 Origin of maize and its domestication

Archaeological examinations of ancient corncobs imply that maize domestication happened between 5000 and 10,000 years ago (Shiferaw et al., 2011) and molecular studies supports these findings. According to Harashima (2007), *Zea mays ssp. parviglumis*, also referred to as a teosinte, is the source of modern domestic maize, having originated about 9000 years ago in the south Mexican valley of the Balsas River. Though maize and teosintes have similar growth forms, taxonomists formerly categorized them in separate genera because of significant differences in plant architecture (Abate et al., 2015). The female inflorescence, also known as the ear, is where the phenotypic differences between the two are visible.

2.2 Maize production in Kenya and its constraints.

Both small-scale farmers and large-scale farmers produce maize across different agro-ecologies of Kenya ranging from the wet low altitudes to the wet high altitudes of the country. The total production ranged between 3.09 to 4.01 million tonnes (*Fig.1a*) with a yield range of between 1.43 to 1.77 t/ha (*Fig. 1b*) in the years 2018 to 2022 (FAOSTAT, 2024). These trends over the five-year period show a decrease in both average production volumes as well as yields per unit production area which can be attributed to shifts in the dynamic of factors affecting production both biotic and abiotic as well as the quality of available germplasm for farmer utilization.

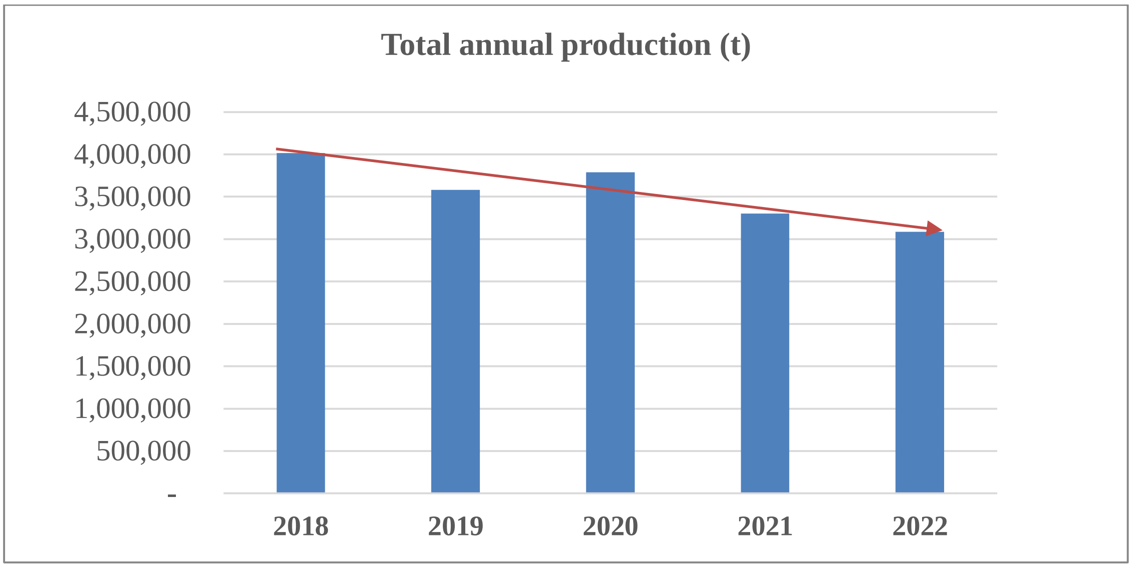

Figure 1a. Total annual maize production in Kenya between 2018 and 2022 (FAOSTAT, 2024).

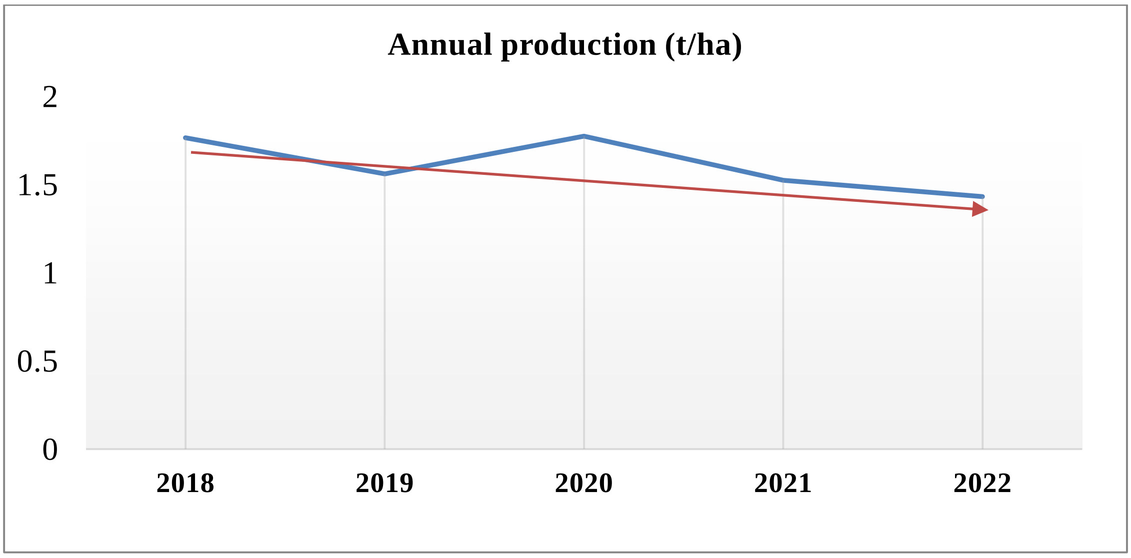

Figure 1b. Average annual yields in t/ha for maize in Kenya between 2018 and 2022 (FAOSTAT, 2024).

Some of the significant constraints to maize production in Kenya are drought, fall armyworm and poor nutrition. Daryanto et al., (2016) reported that drought causes a seasonal decline in maize yields of as much as 39% in most of sub-Saharan Africa. Similarly, CIMMYT (2013) notes that frequent droughts, which affect 25% of the maize-growing regions, could lead to yield losses of up to 50% during the growing season. This report also intimates that 40% of maize areas face occasional droughts, which lead to yield reductions ranging between 10 to 25%.

Two of the major parasitic constraints to maize production are striga and Fall armyworm (FAW). The striga weed (*Striga hermonthica*), commonly known as "witch-weed," is a parasitic plant that affects cereals like maize. For survival, striga extracts nutrients from the hosts by penetrating their root tissues, leading to nutrient deficiencies. Yield loss magnitudes are dependent on the severity of the infestation and the host plant's resistance, with some plants experiencing very low or no yields at all (Ejeta, 2007). In the 1990s, striga was believed to affect 50 to 100 million hectares in sub-Saharan Africa (Lagoke et al., 1991; Kanampiu et al., 2018), causing yield reductions ranging from 20% to 80% (Khan et al., 2006; Ejeta, 2007).

Fall armyworm (*Spodoptera frugiperda* JE Smith) commonly referred to, as "FAW" is an insect pest having its origin in the Americas and with a first reported presence in Africa in early 2016 (Goergen et al., 2016). FAW has the remarkable ability to migrate over long distances on prevailing winds, lay several millions of eggs, and thrive in a variety of plant hosts and environments (Day et al., 2017; Prasanna et al., 2018). By 2018, it had been reported in 30 countries across Africa, including Kenya, with estimated yield losses of up to 40% in Ghana and Zambia (Day et al., 2017), 47% in Kenya, and 32% in Ethiopia (Kumela et al., 2019)

De Groote et al., (2020) notes that over 80% of farmers in Kenya were affected by FAW and experienced losses of over 30% of their crops, with variations observed across ecological zones. Prasanna et al., (2018) suggested that deployment of a range of integrated pest-management practices (IPMs) could manage the FAW.

A maize crop requires a significant supply of nutrients and is particularly sensitive to deficiencies, especially nitrogen (Emede & Alika, 2012). Additionally, achieving the high yield potential of maize often necessitates large quantities of nutrients (Arisede et al., 2020), yet many soils in Africa are lacking in essential macronutrients (Drechsel et al., 2001; Pasley et al., 2020). Smaling et al., (1993) estimated that maize production depletes about 42 kg of nitrogen per hectare each year. However, many farmers are unable to apply sufficient nutrients due to financial constraints, a long-standing challenge (Kamara et al., 2006).

2.3 Hybrid maize breeding

Crow (1998) states that the techniques outlined by Shull (1909) and observations made more than a century ago served as the foundation for the modern hybrid maize industry. Because of the crop's hybrid character, inbred line development and hybrid commercialization have emerged as the two primary components of modern maize breeding globally (Duvick and Cassman, 1999).

In maize breeding, identification and recognition of genetic gains in commercial hybrids is best done if they occur during inbred line development phases which produce the largest *de novo* genetic variation through allelic recombinations and new alleles and allele formation. Heterotic groups made up of inbred lines are further divided into families within each other. As a result, combining a line from one heterotic pattern with a line from another produces a modern hybrid. Over time, classification of heterotic patterns has resulted in the description of between two and seven distinct patterns (Troyer, 1999; Lu & Bernardo, 2001; Gethi et al., 2002; Mikel & Dudley, 2006), following several criteria, including pedigree, molecular marker-based associations, and performance in hybrid combinations (Smith et al., 1990).

Breeding concepts and methods have evolved, embracing new developments in genetic theory and breeding, such as Sprague's 1946 proposal of early-generation testing (El-Lakany & Russell, 1971), quickly implementing advances in modern pesticide chemicals and plant population densities, and understanding how to assess a genotype's genetic potential through improved data analysis and experimental design. While some changes are concentrated on one of the two maize breeding activities, others, such as implementing better management practices, affect both the development of inbred lines and the commercialization of hybrids.

2.4 Heterosis and heterotic classification

The phenomenon known as "heterosis," initially described by Shull in 1909, occurs when the mean of any character or characteristic in a cross is greater than the mean of its progeny produced by any system of close inbreeding. Various theories have been put forth to account for this which include dominance hypothesis, heterozygosis hypothesis,pseudo-over dominance as well as over dominance. Dominance hypothesis, suggests that the combination of distinct dominant alleles from each parent contributes to the increase in vigour following crossing. The heterozygosis hypothesis suggests that the increased vigour is caused by loci where the heterozygous state is better than either homozygote (East & Hayes, 1912; Shull, 1911). According to the pseudo-over dominance heterosis is proposed to be due to highly linked genes with favourable dominant alleles in the repulsion phase in the parental lines for the hybrid's vigour. There appears to be over dominance when combined in the hybrid (Crow, 1952) additionally the epistasis hypothesis, which explains the enhanced vigour in the context of the interaction of advantageous alleles from two parents at various loci that exhibit dominant, additive, and/or over-dominant action (Schnell & Cockerham, 1992). Heterozygosis rose to prominence among these theories.

A breeding germplasm collection which shows enhanced levels of heterosis when crossed to a different germplasm pool greater than when crossed to a member of its original source pool can be defined as a heterotic group (Lee, 1995). Another definition of a heterotic group as provided by Ankinwale, 2021 was a grouping of related or unrelated genotypes from the same or separate populations that exhibit comparable combining ability and heterotic response when crossed with genotypes from other genetically dissimilar germplasm groupings. In the same line, a heterotic pattern can be defined as a particular pair of two heterotic groups that exhibit high levels of heterosis and, as a result, high levels of hybrid performance when they cross (Wang, 2015).

Exploiting heterotic patterns provides a vital source of information for hybrid breeding (Laude et al., 2015). Although the genetic gain of maize inbred lines is the primary focus, breeders often want to produce a superior performance of hybrids when one line is crossed with another from a different group (Ertiro et al., 2017). However, this does not necessarily imply that all hybrids produced between parents of different heterotic groups would always obtain high yield or heterosis, but only parental crosses between certain specific groups do (Wang et al., 2015).

When data on the hybrid performance of different heterotic groups becomes available (Zhao et al., 2015), it can identify the most promising heterotic pattern based on existing breeding information. Plant breeders utilize various techniques to categorize parents into heterotic groups once they have established a notable degree of genetic variety among their parental materials. (Ankinwale, 2021). Due to their high precision and limited sensitivity to environmental influences, genetic and molecular procedures are the favored approaches at an advanced breeding stage.

The mating designs commonly used in plant breeding to categorize parents into heterotic groups are; line × tester mating design is used in breeding programs where there are tested testers, with each tester representing a heterotic group. The North Carolina Design II and the diallel approach are superior substitutes in situations when there are no reliable testers. Information on heterotic groups and tester identification are often the main goals for studies that use these methods.

2.5 Combining ability in maize

Fasahat et al (2016) describe combining ability or productivity in crosses as the cultivars' or parents' ability to combine among each other during the hybridization process such that desirable genes or characters are transmitted to their progenies. Combining ability evaluates the genotypes' worth based on how well their progeny function in a particular mating scheme (Allard, 1960). According to Vasal et al., (1986), parent plants must generate strong off springs to be considered to have superior combining ability.

Sprague and Tatum (1942) first described combining ability as either general or specific combining ability. In the context of maize, general combining ability (GCA) is the mean behaviour of a line in a hybrid, whereas specific combining ability (SCA) is the deviation of crosses based on the average performance of the lines involved (Makumbi, 2005). According to Sprague and Tatum (1942), GCA results from gene activity that mostly has additive effects with additive × additive interactions (Griffing, 1956a). GCA is associated with additive genetic effects, while specific combining ability is associated with non-additive genetic effects (Falconer & Mackay, 1996).

The relative relevance of GCA and SCA in plant breeding has been assessed using a variety of techniques (Fasahat et al. 2016). The first stage in the process is examining the significance of both GCA and SCA at $p<0.05$ or at higher probability (0.01 or 0.001) thresholds. Epistatic gene effects might be crucial in defining these features if neither the GCA nor the SCA values are substantial (Fehr, 1993).

Numerous methods for estimating the GCA and SCA effects have been proposed

and developed in tandem with the rapid advancements in biometrics. Breeders use the following methods to estimate combining ability in different plants: triallel cross by Rawlings & Cockerham (1962), partial diallel cross by Kempthorne & Curnow (1961), North Carolina design by Comstock & Robinson (1948), poly cross technique by Tysdal et al., (1942), top cross method by Davis (1927), developed by Jenkins and Brunaon (1932), and poly cross analysis by Griffing (1956b).

2.6 Line by Tester mating design

Sharma (2006) cites Kempthorne's 1957 proposal for the line × tester mating design, a design that creates X×Y = XY hybrids through a one-to-one hybridization of lines (X) and wide-based testers (Y) (Sharma, 2006). Because the two (lines and the testers) have different genotype sets, the analysis of this mating system yields not only the SCA of each cross but also the GCA of both lines and the testers.

A reliable criterion for selecting an appropriate tester is knowledge of the tester's performance and the genealogy of the test genotypes. It is important to remember that no single tester can meet every requirement in every circumstance, as a tester's value is mostly based on how well they employ a particular set of lines. When assessing lines with an unknown origin, for instance, at least two testers from recognized heterotic groups are used to ascertain the heterotic orientation of fresh lines (Fasahat et al., 2016). Where the goal is to split a large population into two heterotic groups, at least two elite lines from opposing heterotic groups or demonstrating significant degrees of heterosis between them can be utilized as tests. Two lines used as testers make up the best hybrid in the program at the moment in a single-cross hybrid-oriented program. An excellent single cross-hybrid with remarkable combining ability would be a good candidate for a tester in programs concentrating on three-way cross-hybrids of different origins (Fasahat et al., 2016). For instance, combinations of maize inbred lines CML444 and CML395, as well as CML442 and CML312, are used as B and A single cross testers of this type at CIMMYT in eastern and southern Africa. However, the tester can be a single cross of sister lines of the same heterotic group but with high yield potential (Fasahat et al, 2016).

2.7 Grey leaf spot and Northern leaf blight maize diseases in Eastern Africa

2.7.1 Grey leaf spot (GLS)

He et al., (2018) and Crous et al., (2006) both mention *Cercospora zeae-maydis* and *Cercospora zeina* as the polycyclic pathogens responsible for one of the main foliar diseases of maize, known as Grey leaf spot (GLS). *Cercospora zeae-maydis* is found in greater abundance in eastern Africa with predicted yield losses of more than 70%

(Liu et al., 2016) under ideal circumstances presents a significant threat to maize production.

After times of high humidity, *Cercospora zeae-maydis* only infects maize and releases spores (Ward et al 1999). The lower leaves get the spores, which are carried by the wind and rain, and these lesions, begin to form there. They are rectangular in shape and range in length from 1 to 3 mm. Mature lesions, which run parallel to the leaf veins, develop into Grey or brown colored patches. As the leaves develop higher, the number of lesions will quickly rise. The leaf will eventually wilt completely, causing serious lodging and stalk degeneration (Ward et al 1999). At the surface of the soil during intercrop times, this fungus can thrive in infested maize crop remains.

2.7.2 Northern leaf blight (NLB)

Another significant global maize disease is northern leaf blight, which is brought on by the fungus *Exserohilum turcicum* (Pass.) (Leonard & Suggs, 1974; Ndung'u, 2021; Ahangar et al., 2022). In the mid-altitude tropical and sub-tropical regions having moderate temperatures (17°C–28°C), cloudy weather and high rainfall and high humidity, the incidences of NLB have been reported to be prevalent with the pathogen showing high abandunce and pathogen diversity ((Rashid et al., 2020; Bankole et al., 2023). Blighting of the leaves caused by infection results in decreased photosynthesis and, consequently, less grain filling (Paliwal et al., 2000). The fungus spreads by wind and rain to young plants and can endure the winter in contaminated agricultural waste. The fungus appears to be more common in systems with less tillage techniques and higher nitrogen fertilizer use.

The incidence of NLB disease has been rising in the areas that produce maize. According to Vivek et al. (2010), there has been a rise in NLB incidence and severity, particularly in Southern Africa. The primary theories for the rise in incidence included the introduction of temperate germplasm into tropical conditions, which led to an increase in the severity of NLB, and the breakdown of qualitative resistance, which is not stable. For example, in Ethiopia, NLB incidence has been observed to range from 95 to 100% in places with high humidity and persistent wetness. Yield losses have also been recorded to reach 70% (Tewabech et al., 2012). According to reports, NLB severely damages the majority of commercial varieties of maize introduced in that nation (Tewabech et al., 2012).

Although breeding for host resistance is thought to be the best way to reduce yield losses due to this disease, farming practices like crop rotation, seed treatment, and fungicide application have been recommended (Khedekar et al., 2010; Tajudin et al., 2018).

2.8 Multi-environment trials (METs) and the alpha lattice experimental design.

For maize breeders, as with breeders of other crops, the application of suitable statistical methods for selecting genotypes with superior performance across varying environmental conditions is crucial to accelerating genetic gains in breeding programs. These genotypes are typically evaluated through trials conducted in either single or multiple environments (across locations and/or years), under varying management regimes such as water stress, low nitrogen, or optimal conditions (Alvarado et al., 2020). Such evaluations are referred to as multi-environment trials (METs), which are instrumental in assessing genotype performance consistency (repeatability) and the nature of genotype × environment (G×E) interactions. METs also provide estimates of genetic parameters such as broad-sense heritability, which reflect the reliability of genotype performance across environments (Cooper & DeLacy, 1994).

The effectiveness of METs largely depends on the experimental design employed, as it minimizes experimental error and enhances the precision of genotype performance estimates by accounting for spatial variability (Oehlert, 2010). Commonly used designs in METs include randomized complete block designs (RCBD) and incomplete block designs such as lattice and alpha-lattice designs. The choice of design depends on the number of genotypes under evaluation and the level of field heterogeneity. For trials involving a small number of genotypes (<10) in relatively uniform field conditions, RCBD is typically appropriate. In contrast, when evaluating a large number of genotypes (>10) under variable soil and environmental conditions, incomplete block designs such as alpha-lattice designs offer greater efficiency by reducing experimental error.

Balanced incomplete block designs (BIBDs) aim to ensure that all genotype pairs occur together in blocks with equal frequency, thus achieving equal precision in comparing genotype pairs. However, BIBDs are often only feasible in small-scale trials due to their stringent design constraints. In larger trials, perfect balance is rarely attainable, resulting in unequal precision for genotype comparisons.

To address the limitations of BIBDs in large-scale trials, various lattice designs have been developed, with alpha-lattice designs introduced by Patterson and Williams (1976) being among the most widely used (Juma, 2012). In these designs, genotypes are arranged in incomplete blocks within replicates, allowing adjustment of genotype means for block effects such as soil variability. This improves the accuracy of genotype performance estimates and enhances the overall efficiency of selection in breeding programs.

2.9 Heritability

Holland et al., (2003) note that heritability was originally defined by Lush (1940) as the proportion of phenotypic variance attributable to heritable genetic differences among individuals within a population. In plant breeding, candidate genotypes or cultivars are evaluated across multiple environments defined by specific location and season combinations through multi-environment trials (METs) to assess their performance and stability (Giovanni, 2019). Heritability, whether broad-sense (H^2) or narrow-sense (h^2), is typically estimated using genotype means in METs to evaluate the precision and reliability of phenotypic selection across environments.

Broad-sense heritability (H^2) represents the proportion of total phenotypic variance that can be attributed to total genetic variance, encompassing additive, dominance, and epistatic genetic effects (Holland et al., 2003; Falconer & Mackay, 2005; Schmidt et al., 2019). Estimating H^2 for key traits in a given germplasm is crucial, as it informs the breeder of the potential for genetic improvement. High heritability estimates indicate greater efficiency in selection, thereby accelerating genetic gains and enabling the development and release of superior cultivars that align with farmer and market demands.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Germplasm development

A set of 65 yellow maize inbred lines (S_6 generation) from CIMMYT-Asia, selected for tropical adaptation, were introduced into a hybrid development program targeting Kenya’s mid-altitude regions by Western Seed Company. During the 2022 short rains at KALRO-Kibos station (at latitude 0°2' S and longitude 34°48' E, at 1193 masl). The lines were crossed with two testers CML 486 (group A, intermediate maturity, soft dent) and CML 451 (group B, late maturity, soft flint) using a line-by-tester mating design to produce F_1 hybrids. Both testers are adapted to mid-altitude ecologies and possess good combining ability and moderate foliar disease tolerance (CIMMYT, 2005).

The isolated crossing nursery blocks consisted of single row plots of 4m long and 0.2m in between hills with 4 plots of female rows and 1 male row (Tester) in between as a pollinator where all female rows were detasseled at flowering. At harvest, researchers harvested all ears from individual female plots separately, dried them, shelled them, and labelled them appropriately. The study used the resulting 130 F_1 hybrids from the 65 lines crossed with both testers, along with three check varieties, in the multi-environment testing (Appendix II).

Table 3.1 Yellow maize inbred lines used in the study

Line	Pedigree	Line	Pedigree	Line	Pedigree
L1	YM21-100-B	L25	YM21-1-B	L49	YM21-50-B
L2	YM21-112-B	L26	YM21-202-B	L50	YM21-52-B
L3	YM21-116-B	L27	YM21-203-B	L51	YM21-54-B
L4	YM21-118-B	L28	YM21-211-B	L52	YM21-5-B
L5	YM21-123-B	L29	YM21-213-B	L53	YM21-61-B
L6	YM21-124-B	L30	YM21-223-B	L54	YM21-62-B
L7	YM21-129-B	L31	YM21-228-B	L55	YM21-68-B
L8	YM21-12-B	L32	YM21-22-B	L56	YM21-69-B
L9	YM21-131-B	L33	YM21-231-B	L57	YM21-73-B
L10	YM21-136-B	L34	YM21-234-B	L58	YM21-81-B
L11	YM21-140-B	L35	YM21-249-B	L59	YM21-85-B
L12	YM21-155-B	L36	YM21-256-B	L60	YM21-91-B
L13	YM21-157-B	L37	YM21-257-B	L61	YM21-92-B
L14	YM21-166-B	L38	YM21-258-B	L62	YM21-95-B
L15	YM21-167-B	L39	YM21-265-B	L63	YM21-97-B
L16	YM21-168-B	L40	YM21-267-B	L64	YM22-15
L17	YM21-16-B	L41	YM21-26-B	L65	YM22-3
L18	YM21-172-B	L42	YM21-288-B	**Check1**	YM020-5×TA
L19	YM21-17-B	L43	YM21-297-B	**Check2**	YM020-9×TA
L20	YM21-186-B	L44	YM21-36-B	**Check3**	WY21
L21	YM21-187-B	L45	YM21-3-B	**TESTER-A**	CML486
L22	YM21-18-B	L46	YM21-42-B	**TESTER-B**	CML451
L23	YM21-190-B	L47	YM21-47-B		
L24	YM21-198-B	L48	YM21-48-B		

L1- Line 1, L2- Line 2…. L65

3.2 Description of experimental sites

The field evaluation of F1 testcrosses was conducted during the main season of 2023 across two mid-altitude and one highland agro-ecological zone in Kenya, specifically in Kakamega, Bungoma, and Trans-Nzoia counties, as outlined in Table 3.2.

Table 3.2 Description of the agro-ecological zones of the study sites with annual rain fall and temperature ranges.

Site	County	Longitude	Latitude	Altitude (masl)	Rainfall (mm)	Temperature (°C)
Chorlim	Trans-nzoia	1.03131	34.8459	1910	1200	21-35
Mabanga	Bungoma	0.6016	34.6262	1503	1100	19 -32
Shikusa	Kakamega	0.32291	34.8121	1574	1600	21- 33

Sources: Jaetzold et al (2005), Mugalavai et al (2008), Dixit et al (2011).

3.3 Experimental design and field management

One hundred and thirty F_1 hybrids developed by crossing 65 yellow maize inbred lines with two testers along with three yellow maize check varieties were evaluated using a 7×19 alpha lattice design (Paterson & Williams, 1976), randomised with Field-Book software (Bänziger et al., 2020) with two replications on three sites.

Before the 2023 long rains, trial fields were ploughed and harrowed, then uniformly laid out in areas with minimal slope and soil variation. Each plot had a single 5 m row, spaced 0.75 m between rows and 0.25 m between hills. Two seeds per hill were sown and later thinned to one at two weeks after planting, targeting a plant population of 53,333 plants/ha. Two border rows were planted to reduce edge effects.

Fertilization included 187 kg/ha of DAP at planting and 187 kg/ha of CAN at the eighth leaf stage (KEPHIS, 2020). Other crop management practices including weed and pest control were carried out throughout the season.

3.4 Data collection

Phenotypic data on grain yield and yield-related traits were collected throughout the growing season until harvest following the procedures below, as described by Badu-Apraku et al. (2012).

Anthesis Date (AD) was were recorded as the number of days from trial planting to the day when 50% of plants in a plot reach pollen shed.

Ear Height (EH) and Plant Height (PH) were measured as the average heights from the ground to the insertion of the uppermost ear, and from the base of the plant to the insertion of the first tassel branch, respectively. These measurements were taken in centimetres on five representative plants per plot, three weeks post-flowering.

Ear Rot (ER) was calculated as the percentage of harvested ears per plot affected by ear rot, while Husk Cover (HC) was determined as the percentage of ears per plot exhibiting loose or open tips.

Plant Aspect (PA) was visually rated on a scale from 1 to 5 based on the overall appearance of the plants in each plot. A score of 1 indicated a plot with uniform plants, good ear position, and strong yield potential, while a score of 5 indicated a plot with poor plant types, irregular plants, poor ear position, and low yield potential (Badu-Apraku et al., 2012).

Ear Aspect (EA) was visually rated on a 1-5 scale based on the overall appearance of the cobs in each plot. A score of 1 indicated uniform cobs with good texture and yield potential, while a score of 5 indicated irregular cobs with deformities, ear rot, poor texture, and low yield potential (Badu-Apraku et al., 2012).

Northern Leaf Blight and Grey Leaf Spot diseases were visually rated based on the severity of visible disease symptoms on the leaf area using a scale from 1 to 5. A score of 1 indicated no visible disease symptoms (asymptomatic plants), while a score of 2 indicated diseased leaves extending up to the point of ear insertion. A score of 3 was assigned when large lesions were visible on leaves both below and above the ear, and a score of 4 was assigned for severe lesions on all leaves, although the upper leaves remained affected. A score of 5 indicated a plot where all leaves were dead.

Grain yield (GY) (t/ha) was obtained by adjusting field weight of the total ears per plot using the moisture content of the plot to give the plot’s grain yield in tons per hectare using the formula;

$$GY = (\left(\frac{FW}{1000}\right) \times \left(\frac{100-Moi}{100-12.5}\right) \times \left(\frac{100}{A}\right) \times P)$$

Where: FW=weight of all cobs per plot (in Kg), MOI=grain moisture content (in percentage), A= the plot's net area, calculated as [number of hills × spacing between hills (m) × spacing between rows (m)], and P= shelling percentage of 0.8 if cobs were to be shelled.

3.5 Data analysis

3.5.1 Hybrid performance, heritability and phenotypic correlations.

Estimation of variance components, means using best linear unbiased estimates (BLUEs) and broad sense heritability were executed using META-R (Multi-Environment Trial Analysis in R for Windows) Version 6.0 (Alvarado et al., 2015). This utilised the linear models developed in the *lmer* function from the *lme4* package in R by applying the REML (Restricted Maximum Likelihood) method.

The model used for analysing individual environments with a lattice design was as follows:

$$Y_{ijk} = \mu + Rep_i + Block_j(Rep_i) + Gen_k + \varepsilon_{ijk} \text{ ………………….. Equation 2}$$

Where Y_{ijk} is the trait of interest, μ is the mean effect and Rep_i is the effect of the ith replicate. $Block_j$ was the effect of the jth incomplete block within the ith replicate. Similarly, Gen_k is the effect of the kth genotype, ε_{ijk} is the error associated with the ith replication, jth incomplete block and the kth genotype, which is assumed the data to be normally and independently distributed, with mean zero and homoscedastic variance σ^2 (Alvarado et al, 2020).

Inclusion of the following terms to the aforementioned model allowed for performance of across sites analysis for all environments:

$$Yijk = \mu + Env_i + Rep_j(Env_i) + Block_k(Env_i Rep_i) + Gen_l + Env_i \times Gen_l + \varepsilon jkl_l \text{ … Equation 3.}$$

where Env_i and $Env_i \times Gen_l$ are the effects of the ith environment and the environment by genotype interaction, respectively.

With a 95% confidence level, genotypes were used as random effects to calculate BLUEs for every characteristic.

A trait's broad-sense heritability in a particular environment was determined to be

$$H^2 = \frac{\sigma_g^2}{\sigma_g^2 + \sigma_e^2/nrep} \text{ …………… Equation 4.}$$

where σ_g^2 and σ_e^2 were the genotype and error variance components, respectively, and *nreps* was the number of replicates.

The heritability was calculated for the combined analyses as follows

$$H^2 = \frac{\sigma_g^2}{\sigma_g^2 + \frac{\sigma_{ge}^2}{nrep} + \frac{\sigma_g^2}{nEnvs\ x\ nRep}.} \text{ .... Equation 5.}$$

where *nEnvs* was the number of environments in the analysis and the new term $\sigma_{ge}^2$was the genotype by environment interaction variance component.

The LSD computation was as follows and used to separate the means at the 5% level of significance:

$$LSD = t_{(1-0.05,dfErr)} \times ASED \text{....................... Equation 6.}$$

Where *t* is the cumulative Student's t distribution,

0.05 is the α selected level of significance to 5%,

dfErr is the degrees of freedom for the variance of error, and ASED was the average standard error of differences between pairs of means.

The formula below was used to find the percent coefficient of variation.

$$CV = \left(\frac{ASED}{grand\ mean}\right). \text{ .... Equation 7.}$$

Simple Pearson correlations were used to identify phenotypic relationships between traits (Pearson, K. 1920). BLUEs from individual and across sites were used to compute the phenotypic correlation matrices with assigned significance levels using the R package ‘corrplot’, (Wei & Simko, 2024).

3.5.2 Combining ability analysis

This study aimed to assess the combining abilities of inbred lines; both general combining ability (GCA) for lines and specific combining ability (SCA) for hybrids based on grain yield and related traits at individual sites and across multiple environments. The analysis was performed using CIMMYT’s AGD-R software (Rodriguez et al., 2015), applying the Henderson method for balanced data, based on the linear model below:

$$Y_{ijk} = \mu + E_d + Rep_k(E_d) + l_i + t_j + l_i \times t_j + E_d \times l_i + E_d \times t_j + E_d \times l_i \times t_j + Blk(Rep_k) + \varepsilon_{ijk} \ldots\ldots \text{ Equation 8.}$$

Y_{ijk} is the observed value is the general mean, E_d is the environmental effect (d = 1,2,... s), $Rep_k(E_d)$ is the effect of replicate k nested in environment d (k = 1,2, …, r) l_i is the line effect (i = 1,2,…,m) t_j is the tester effect (j = 1,2,…, f) $Blk(Rep_k)$ random effect of block nested in replicate k ε_{ijk} is the residual.

3.5.3 Heterotic classification of the inbred lines

Heterotic grouping followed a procedure described by Gebre (2021) based on the SCA effects of the line with the testers for grain yield. Lines with positive SCA effects for grain yield with Tester A were placed in the opposite heterotic group, B, along with lines showing negative SCA effects with Tester B. Similarly, lines with positive SCA effects for grain yield with Tester B were assigned to heterotic group A, along with lines exhibiting negative SCA effects with Tester A. Lines that did not align with the same heterotic group for both testers were excluded from the grouping

CHAPTER FOUR

RESULTS

4.1 Hybrid performance, heritability and phenotypic correlations study

4.1.1 Hybrid performance and heritability at Chorlim

At Chorlim, genotypic variance for all traits was highly significant ($p < 0.01$ and $p < 0.001$) (Table 4.1). Grain yield ranged from 1.9 to 14.3 T/Ha, with a mean of 10.2 T/Ha. Days to anthesis varied between 73 and 88 days (mean, 80 days). Plant height ranged from 196.2 cm to 298.0 cm (mean, 260.7 cm), and ear height from 82.6 cm to 168.6 cm (mean, 133.4 cm).

Husk cover ranged from 0% to 100%, averaging 36.9%, while ear rot damage ranged from 0% to 42.7% (mean, 11.06%). Grey Leaf Spot and Northern Leaf Blight scores averaged 2.9 and 2.4, respectively. Among the hybrids, L40×TA recorded the highest grain yield (14.0 T/Ha), while Check 2 had the highest overall yield at 14.3 T/Ha (Table 4.2; Appendix III).

Differences in the heritability and high genotypic significance on all studied traits were observed at Chorlim (Table 4.1). High heritability (≥ 60%) was recorded for grain yield, anthesis date, plant height, ear height, ear position ratio, husk cover, ear rot, Grey leaf spot and Ear aspect 72 and 91% respectively. Northern leaf blight and Plant aspect had moderate heritability (30-60%) at 55%, 44% and 48% respectively.

Table 4.1 Summary statistics, variance component estimates, and heritability for grain yield, yield-related traits at Chorlim.

Trait	**Mean**	**Range**	$\hat{\sigma}^2_G$	$\hat{\sigma}^2_\varepsilon$	H^2	$LSD_{0.05}$	*CV*
GY	10.0	1.9-14.3	3.76***	0.97	0.89	1.92	9.85
AD	80	73-88	7.86***	1.90	0.89	2.79	1.72
PH	260.7	196.2-298.0	272.92***	61.70	0.90	15.65	3.01
EH	133.4	82.6-168.6	229.47***	44.89	0.91	13.43	5.02
HC	36.9	0-100	957.91***	207.13	0.90	27.95	39.00
ER	11.0	0-42.7	83.24***	41.58	0.80	11.97	58.33
GLS	2.9	1.5-5.0	0.61***	0.23	0.84	0.89	16.35
NLB	2.4	1.5-4.1	0.08**	0.20	0.44	0.61	18.72
EA	2.6	1.7-4.0	0.14***	0.10	0.72	0.55	12.35
PA	2.8	2.0-4.0	0.09***	0.19	0.48	0.61	15.57

, *: Significant at $p<0.01$, and $p<0.001$ respectively. GY, grain yield (T/Ha); AD, days to 50% anthesis; PH, plant height (cm); EH, ear height (cm); HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect; $\hat{\sigma}^2_G$,genetic variance, $\hat{\sigma}^2_\varepsilon$ residual variance H^2, Heritability, $LSD_{0.05}$, least significant difference; CV, coefficient of variation

Table 4.2 Hybrid performance of the best and least five testcrosses and checks for grain yield and yield related traits at Chorlim

Genotype	Testcross	Grain Yield *T/Ha*	Anthesis date *#days*	Plant height *cm*	Ear height *cm*	Husk cover *%*	Ear rot *%*	Grey leaf spot *(1-5)*	N. leaf blight *(1-5)*	Ear aspect *(1-5)*	Plant aspect *(1-5)*
79	L40xTA	14.0	81	272.5	158.3	63.6	0.8	1.5	2.1	2.3	3.0
70	L35xTB	13.6	86	269.5	148.6	0.6	9.6	2.0	2.0	2.2	2.0
69	L35xTA	13.3	81	292.3	168.6	29.4	14.0	2.5	2.1	2.5	2.5
75	L38xTA	13.3	76	284.5	146.8	87.7	4.3	2.0	2.5	3.0	3.0
89	L45xTA	13.1	82	276.6	152.7	86.2	1.2	1.5	1.9	2.5	3.0
48	L24xTB	4.7	83	214.3	87.5	0.4	42.7	3.0	2.1	3.5	3.5
58	L29xTB	4.2	87	234.5	111.1	1.5	34.9	5.0	2.4	3.8	4.0
130	L65xTB	3.8	85	205.6	98.1	44.7	26.3	3.5	2.4	3.5	3.5
16	L8xTB	3.4	85	197.1	82.6	-2.4	16.8	4.5	1.9	3.5	4.0
46	L23xTB	1.9	88	196.2	84.1	-0.5	31.6	5.0	2.9	4.0	4.0
131	YM020-5xTA	12.3	79	268.2	130.2	30.4	16.2	2.0	2.0	2.8	3.0
132	YM020-9xTA	14.3	80	271.3	133.1	66.9	10.2	2.0	2.6	2.5	3.0
133	WY21	13.9	78	272.3	138.4	9.9	19.0	3.0	2.6	2.0	2.0
	Mean	10.0	80	260.7	133.4	36.9	11.1	2.9	2.4	2.6	2.8

4.1.2 Hybrid performance and heritability at Mabanga.

At this site, all traits showed highly significant genotypic variance ($p < 0.001$) (Table 4.3). The average grain yield was 9.0 T/Ha, ranging from 2.8 to 12.4 T/Ha. Days to anthesis averaged 70 days, with the earliest flowering testcross at 64 days and the latest at 76 days.

Mean plant height and ear height were 211.2 cm and 91.7 cm, respectively. Husk cover averaged 28%, while ear rot incidence was relatively low at 4.7%. On a 1–5 scale, Northern Leaf Blight and Grey Leaf Spot had mean scores of 2.7 and 2.8, respectively. The most resistant hybrids scored 1.8 for Northern leaf blight and 1.5 Grey leaf spot, while the most susceptible scored 4.0 and 4.2, respectively.

Ear aspect and plant aspect had average scores of 2.5 and 2.6. Heritability estimates were high ($\geq 60\%$) for most traits: grain yield (0.77), anthesis date (0.79), plant height (0.81), ear height (0.79), husk cover (0.71), Grey Leaf Spot (0.82), Northern Leaf Blight (0.61), and plant aspect (0.65). Moderate heritability (30–60%) was observed for ear rot (0.44) and ear aspect (0.54).

Among the hybrids, L4×TA and L12×TB recorded the highest grain yield (12.4 T/Ha), while Check 3 was the top-performing check at 12.0 T/Ha (Table 4.4; Appendix IV).

Table 4.3 Summary statistics, variance component estimates, and heritability for grain yield, and related agronomic traits at Mabanga.

Trait	**Mean**	**Range**	$\hat{\sigma}_G^2$	$\hat{\sigma}_\varepsilon^2$	H^2	$LSD_{0.05}$	*CV*
GY	9.0	2.8-12.4	2.90***	1.75	0.77	2.30	14.78
AD	70	64 -76	4.80***	2.58	0.79	2.94	2.28
PH	211.2	159.3-241.6	189.28***	89.37	0.81	18.14	4.48
EH	91.7	58.8-154.2	128.25***	66.20	0.79	15.35	8.87
HC	28.0	0-100	563.36***	464.26	0.71	35.99	76.96
ER	4.5	0-21.9	10.58***	26.98	0.44	6.84	110.66
GLS	2.7	1.53-4.2	0.26***	0.11	0.82	0.63	12.61
NLB	2.8	1.8-4.0	0.11***	0.14	0.61	0.58	13.36
EA	2.5	2.0-3.2	0.03***	0.05	0.54	0.34	9.01
PA	2.6	1.9-3.8	0.07***	0.08	0.65	0.46	10.85

***: Significant at $p<0.001$ respectively. GY, grain yield (T/Ha); AD, days to 50% anthesis; PH, plant height (cm); EH, ear height (cm);; HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect; $\hat{\sigma}_G^2$,genetic variance, $\hat{\sigma}_\varepsilon^2$ residual variance H^2, Heritability, $LSD_{0.05}$, least significant difference; CV, Percent coefficient of variation.

Table 4.4 Hybrid performance of the best and least five testcrosses and checks for grain yield and yield related traits at Mabanga

Genotype	Testcross	Grain Yield *T/Ha*	Anthesis Date *#days*	Plant height *cm*	Ear height *cm*	Husk cover *%*	Ear rot *%*	Grey leaf spot *(1-5)*	N. leaf blight *(1-5)*	Ear aspect *(1-5)*	Plant aspect *(1-5)*
7	L4xTA	12.4	72	229.4	110.7	87.5	2.1	2.0	3.0	2.5	2.5
24	L12xTB	12.4	71	228.4	93.8	15.0	2.2	2.5	2.5	2.2	2.0
93	L47xTA	12.1	69	231.2	154.2	100.0	2.4	2.3	2.3	2.5	2.7
89	L45xTA	11.9	69	241.6	94.1	40.5	9.1	2.1	2.8	2.2	2.7
54	L27xTB	11.6	72	198.5	74.9	0.0	4.6	2.2	2.8	2.2	2.3
56	L28xTB	3.8	75	181.8	62.6	50.0	0.0	3.3	2.5	3.0	3.0
46	L23xTB	3.8	74	159.3	58.8	0.0	20.0	4.0	2.3	3.0	3.8
58	L29xTB	3.8	74	197.9	71.0	0.0	8.8	3.3	2.8	3.0	2.8
16	L8xTB	2.9	72	190.2	68.2	0.0	10.4	3.8	2.5	3.0	3.3
130	L65xTB	2.8	75	161.7	62.2	0.0	11.1	2.7	2.5	3.0	3.3
131	YM020-5xTA	10.3	72	209.4	86.3	0.0	4.8	2.5	2.5	2.5	2.5
132	YM020-9xTA	9.6	72	215.4	91.6	16.7	5.6	1.9	3.0	2.5	2.3
133	WY21	12.1	69	211.2	91.2	22.0	9.6	2.2	3.0	2.5	2.3
	Mean	9.0	70	211.2	91.7	28.0	4.7	2.7	2.8	2.5	2.6

4.1.3 Hybrid performance and heritability at Shikusa.

Apart from Northern leaf blight, genotypic variance for all studied traits were significant (*p*<0.001 & *p*<0.01) (Table 4.5). Grain yield means ranged between 2.8T/Ha and 11.9T/Ha with a site mean of 8.0T/Ha. The mean days to anthesis at this site were 72 with a range of between 67 and 81 days. Plant height and ear height ranged between 177 to 265cm and 66.8 to 139cm respectively with site means of 236.8cm and 106.5cm respectively. The percentage bad husk cover and ear rot means for this site were 14.7% and 7% respectively. The best testcross for husk cover had a mean of 0% meaning no bad husk cover was recorded whereas the worst test cross had a mean of 83.6%.

Northern leaf blight and Grey leaf spot had site means of 2.6 and 2.5 on a scale of 1-5. For Grey leaf spot, the least susceptible testcross had a mean of 1.8 and most susceptible had a score of 5.0. The best resistant testcross for Northern leaf blight had a mean of 2.0 whereas the most susceptible had a mean at 3.7. Ranges for ear aspect and plant aspect were 1.8 to 4.0 and 2.0 to 3.3 respectively. Mean for the site for ear aspect was 2.7.

Grain yield (0.72), Anthesis date (0.87), Plant height (0.92), Ear Height (0.90), Ear position ratio (0.84), Husk cover (0.84), Ear rot (0.61) and Ear aspect (0.75) had high heritability (≥ 60%) at this site. Grey leaf spot and Plant aspect at 0.48 and 0.45 respectively showed moderate heritability whereas Northern leaf blight had low heritability (<30%) at 0.13 and 0.02 respectively.

At this site, testcross L45×TA produced the highest mean for grain yield at 11.9T/Ha with Check 2 giving the highest mean for the same traits among the checks at 10.7T/Ha (Table 4.6; Appendix V).

Table 4.5 Summary statistics, variance component estimates, and heritability for grain yield, and related agronomic traits at Shikusa.

Trait	Mean	Range	$\hat{\sigma}_G^2$	$\hat{\sigma}_\varepsilon^2$	H^2	$LSD_{0.05}$	CV
GY	8.0	2.8-11.9	2.07***	1.63	0.72	2.23	16.06
AD	72.5	66.8-81.2	3.38***	1.04	0.87	2.04	1.41
PH	236.8	177-265	226.19***	40.23	0.92	13.22	2.68
EH	106.5	66.8-139.0	172.8***	36.64	0.90	12.35	5.69
HC	14.7	0-83.6	276.05***	106.92	0.84	19.95	70.34
ER	7.0	0-45.3	35.49***	44.62	0.61	10.69	95.44
GLS	2.5	1.78-5.0	0.26***	0.56	0.48	1.05	29.89
NLB	2.6	2-3.7	0.01	0.18	0.10	0.27	16.87
EA	2.7	1.8-4.0	0.19***	0.12	0.75	0.60	12.75
PA	2.5	2-3.3	0.03**	0.07	0.45	0.36	10.81

***: Significant at $p<0.001$ respectively. GY, grain yield (T/Ha); AD, days to 50% anthesis; PH, plant height (cm); EH, ear height (cm); HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect; $\hat{\sigma}_G^2$,genetic variance, $\hat{\sigma}_\varepsilon^2$ residual variance H^2, Heritability, $LSD_{0.05}$, least significant difference; CV, Percent coefficient of variation.

Table 4.6 Hybrid performance of the best and least five testcrosses and checks for grain yield and yield related traits at Shikusa

Genotype	Testcross	Grain Yield *T/Ha*	Anthesis date *#days*	Plant height *cm*	Ear height *cm*	Husk cover *%*	Ear rot *%*	Grey leaf spot *(1-5)*	N. leaf blight *(1-5)*	Ear aspect *(1-5)*	Plant aspect *(1-5)*
89	L45xTA	11.9	72	256.6	129.7	21.2	4.0	2.0	2.5	2.0	2.3
69	L35xTA	11.9	73	258.1	139.0	22.9	11.2	2.0	2.3	2.0	2.3
93	L47xTA	11.1	73	253.7	127.5	48.7	3.2	2.1	2.6	2.3	2.2
67	L34xTA	10.6	73	243.7	120.4	12.9	2.3	2.1	2.2	2.3	2.5
31	L16xTA	10.4	70	229.9	104.5	8.1	0.6	2.1	2.8	2.0	2.3
48	L24xTB	4.0	75	198.1	74.5	10.5	15.2	2.5	2.0	3.8	3.0
50	L25xTB	3.9	76	206.4	84.4	1.6	24.8	3.5	2.3	3.5	2.7
58	L29xTB	3.1	76	219.3	84.9	-2.2	43.9	2.5	2.3	3.8	2.5
46	L23xTB	3.1	78	177.0	66.8	0.8	45.3	3.4	2.5	4.0	3.0
130	L65xTB	2.8	81	181.2	67.7	13.9	5.0	3.6	2.0	4.0	3.3
131	YM020-5xTA	8.5	74	249.7	107.9	2.1	11.5	2.1	2.5	2.3	2.0
132	YM020-9xTA	10.7	73	242.9	114.7	5.4	3.0	2.2	2.2	2.3	2.0
133	WY21	8.5	72	237.9	96.8	9.0	1.9	2.5	2.7	2.5	2.5
	Mean	8.0	72	236.8	106.5	14.7	7.0	2.5	2.5	2.7	2.5

4.1.4 Hybrid performance and heritability across locations.

All traits studied showed highly significant genotypic variance ($p < 0.001$), while genotype × environment (G×E) interactions were also significant ($p < 0.05$) for all traits except plant height, which was not affected by G×E interaction (Table 4.7). Among the test sites, Chorlim recorded the highest mean grain yield, whereas Shikusa had the lowest. Across all sites, grain yield ranged from 2.8 T/Ha to 12.4 T/Ha, with an overall mean of 9.0 T/Ha.

Flowering occurred earliest at Mabanga, followed by Shikusa, and latest at Chorlim. Across all sites, days to 50% anthesis ranged from 69 to 80 days, with an average of 74 days. The tallest plants and highest ear placement were recorded at Chorlim, while Mabanga had the shortest. Across sites, plant height averaged 236.2 cm (range: 176.5 - 267.5 cm), and ear height averaged 110.5 cm (range: 69.7 - 142.8 cm).

Chorlim also recorded the highest means for husk cover and ear rot, while the lowest values were observed at Shikusa (for husk cover) and Mabanga (for ear rot). Grey Leaf Spot scores ranged from 1.84 to 4.7 and Northern Leaf Blight from 2.0 to 3.5, with overall means of 2.70 and 2.59, respectively (on a 1-5 scale). Mean scores for ear and plant aspects across sites were 2.62 and 2.61, respectively.

Broad-sense heritability was high for most traits across environments, ranging from 67% to 94%, except for Northern Leaf Blight, which showed moderate heritability at 46%. Plant height and ear height had the highest heritability (94%).

Hybrid L45×TA recorded the highest grain yield across sites at 12.4 T/Ha, while Checks 2 and 3 each yielded 11.5 T/Ha (Table 4.8; Appendix VI)

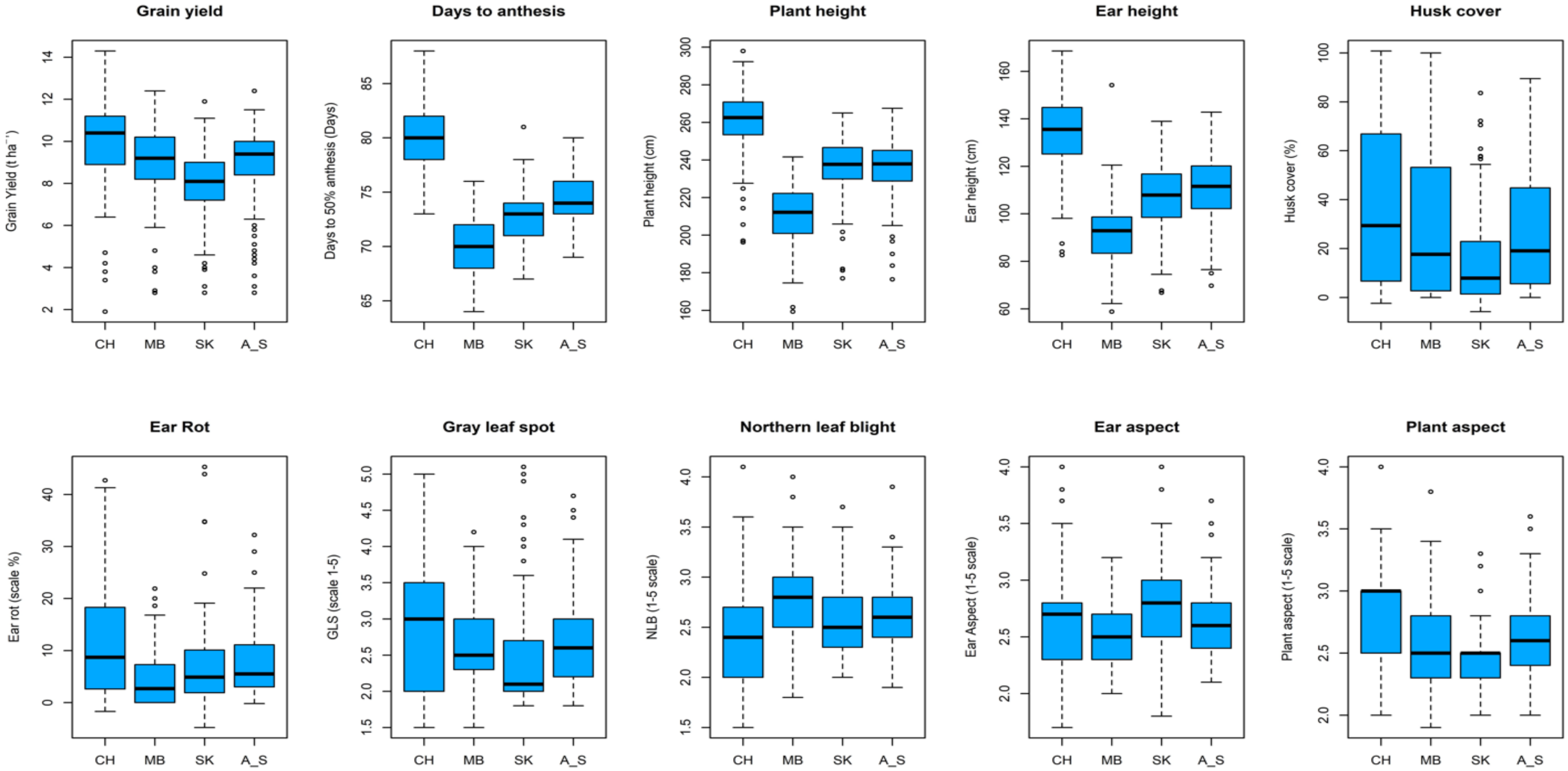

Figure 2: Boxplots for hybrid performance for the studied traits at individual and across sites. CH; Chorlim, MB; Mabanga, SK; Shikusa and A_S; Across sites.

Table 4.7 Summary statistics, variance component estimates, and heritability for grain yield, and agronomic traits across sites

Trait	Mean	Range	$\hat{\sigma}^2_G$	$\hat{\sigma}^2_{GE}$	$\hat{\sigma}^2_\varepsilon$	H_2	$LSD_{0.05}$	CV
GY	9.0	2.8-12.4	2.48***	0.48***	1.39	0.86	1.67	13.13
AD	74	69-80	4.56***	0.79***	1.84	0.89	2.06	1.83
PH	236.2	176.5-267.5	220.19***	7.00	64.16	0.94	10.43	3.39
EH	110.5	69.7-142.8	166.07***	9.51**	48.84	0.94	9.69	6.32
HC	26.5	0-89.5	486.23***	115.5***	271.05	0.85	23.59	62.05
ER	7.6	0-32.2	27.74***	15.63***	37.83	0.71	8.07	81.12
GLS	2.7	1.8-4.7	0.32***	0.05*	0.3	0.83	0.67	20.41
NLB	2.6	2-3.5	0.03***	0.04***	0.18	0.41	0.37	16.29
EA	2.6	2.1-3.7	0.08***	0.04***	0.09	0.74	0.41	11.65
PA	2.6	2-3.6	0.05***	0.01*	0.11	0.67	0.36	12.86

*, **, ***: Significant at $p<0.05$, $p<0.01$, and $p<0.001$ respectively. GY, grain yield (T/Ha); AD, days to 50% anthesis; PH, plant height (cm); EH, ear height (cm); HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect; $\hat{\sigma}^2_G$,genetic variance, $\hat{\sigma}^2_{GE}$ GxE variance, $\hat{\sigma}^2_\varepsilon$ residual variance,H_2, Heritability, $LSD_{0.05}$, least significant difference; CV, coefficient of variation.

Table 4.8 Hybrid performance of the best and least five testcrosses and checks for grain yield and yield-related traits across locations

Genotype	Testcross	Grain Yield *T/Ha*	Anthesis date *#days*	Plant height *cm*	Ear height *cm*	Husk cover *%*	Ear rot *%*	Grey leaf spot *(1-5)*	N. leaf blight *(1-5)*	Ear aspect *(1-5)*	Plant aspect *(1-5)*
89	L45xTA	12.4	74	259.4	125.8	48.5	5.1	1.9	2.4	2.3	2.7
93	L47xTA	11.2	74	249.0	142.8	70.6	1.5	2.3	2.3	2.7	2.7
70	L35xTB	11.0	79	250.9	126.9	2.0	5.3	2.2	2.3	2.1	2.0
69	L35xTA	10.9	76	261.2	140.7	20.4	9.2	2.1	2.2	2.3	2.4
67	L34xTA	10.9	73	248.9	127.7	48.1	4.8	2.2	2.5	2.5	2.7
48	L24xTB	4.4	77	196.7	77.0	2.4	21.8	2.8	2.2	3.4	3.1
50	L25xTB	4.2	79	207.9	97.2	14.3	21.4	3.5	2.5	3.1	2.9
58	L29xTB	3.6	79	217.0	89.2	0.0	29.0	3.6	2.5	3.5	3.1
130	L65xTB	3.1	80	183.8	76.5	18.9	14.0	3.2	2.3	3.5	3.3
46	L23xTB	2.8	80	176.5	69.7	0.0	32.2	4.1	2.6	3.7	3.6
131	YM020-5xTA	10.4	75	243.3	108.8	9.8	11.4	2.2	2.3	2.5	2.5
132	YM020-9xTA	11.5	75	244.5	113.9	27.6	6.3	2.1	2.6	2.4	2.4
133	WY21	11.5	73	241.3	109.6	13.0	10.4	2.6	2.7	2.3	2.3
	Mean	9.0	74	236.2	110.5	26.5	7.6	2.7	2.6	2.6	2.6

4.2 Phenotypic correlations between grain yield and yield-related traits.

4.2.1 Phenotypic correlations at Chorlim.

Figure 3 shows that plant height, ear height, and husk cover exhibited positive and significant correlations ($p<0.001$) with grain yield, while days to anthesis, ear rot, Grey leaf spot, Northern leaf blight, ear aspect, and plant aspect all showed negative and significant correlations ($p<0.001$) with grain yield. Among these, plant height had the strongest positive correlation with grain yield (r = 0.62), while Grey leaf spot showed the strongest negative correlation (r = -0.51).

Ear rot and Grey leaf spot demonstrated positive and significant relationships with days to 50% anthesis, with coefficients of r = 0.29 and r = 0.48, respectively. In contrast, plant height and husk cover had negative significant relationships with days to 50% anthesis at r = -0.25 and -0.48 ($p<0.001$).

Ear height and husk cover both exhibited positive and significant correlations ($p<0.01$) with plant height, with ear height showing the strongest positive correlation (r = 0.79). However, ear rot, Grey leaf spot, ear aspect, and plant aspect had negative and significant correlations with plant height, with ear rot having the strongest negative correlation (r = -0.38).

We found positive and significant correlations between ear height and husk cover (r = 0.30, $p<0.001$), while ear rot, Grey leaf spot, ear aspect, and plant aspect all exhibited negative and significant correlations with ear height, with ear rot showing the strongest negative correlation (r = -0.48).

Ear aspect and plant aspect demonstrated positive and significant correlations with husk cover, with plant aspect showing the strongest positive correlation (r = 0.28, *p*<0.001). On the other hand, ear rot and Grey leaf spot had negative and significant correlations with husk cover, with coefficients of r = -0.40 and r = -0.52, respectively.

Additionally, ear rot showed positive and significant relationships with both Grey leaf spot and ear aspect at r = 0.33 and r = 0.31 respectively. Ear aspect exhibited a positive and significant correlation with plant aspect (r = 0.46, p<0.001).

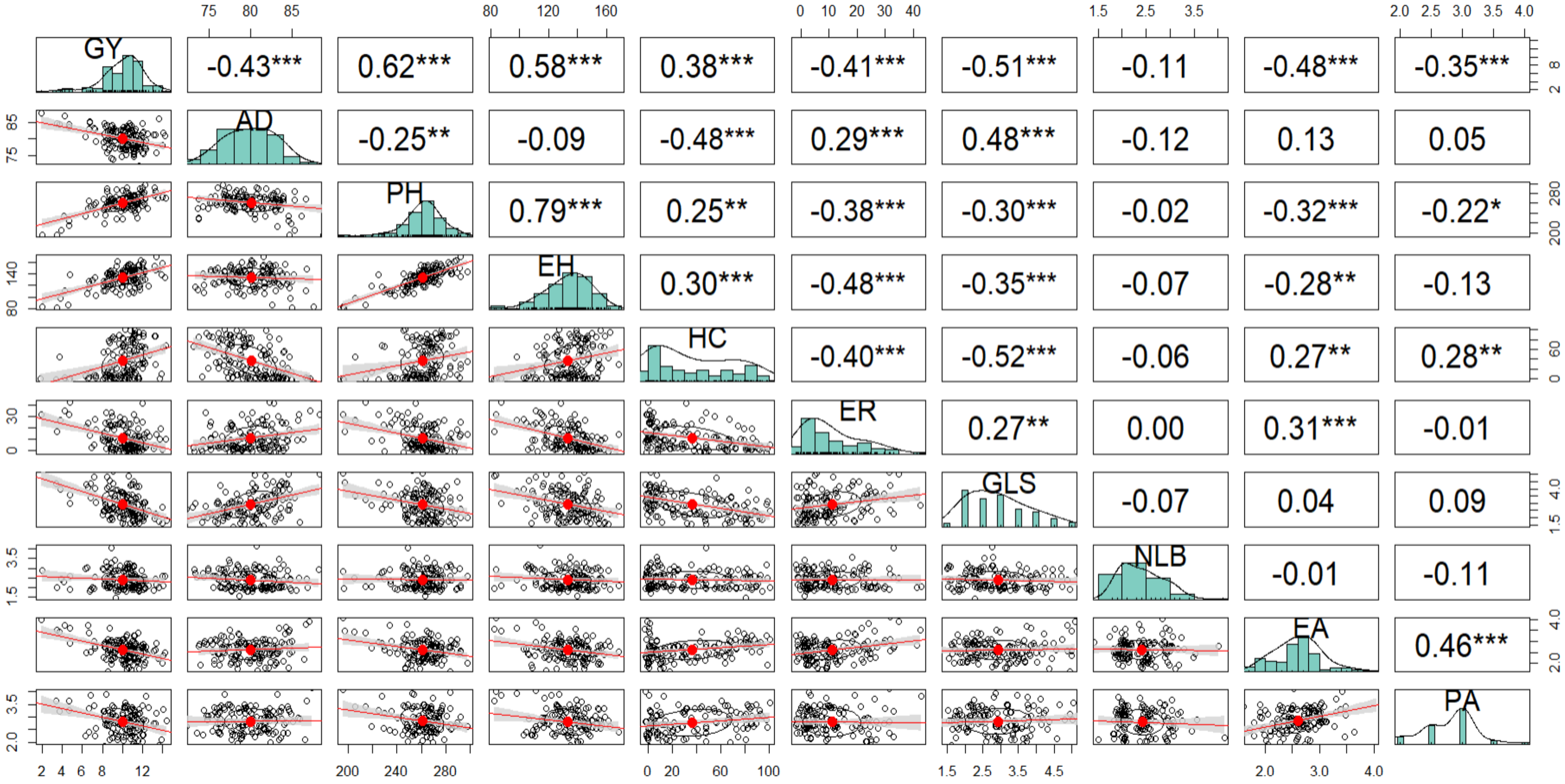

Figure 3. Phenotypic correlations between grain yield and yield related traits at Chorlim. *, **, ***: Significant at *p*<0.05, *p*<0.01, and *p*<0.001 respectively. GY, grain yield; AD, days to 50% anthesis; PH, plant height; EH, ear height; HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect.

4.2.2 Phenotypic correlations at Mabanga.

Figure 4 shows that days to 50% anthesis, ear rot, Grey leaf spot disease (GLS), ear aspect, and plant aspect all exhibited negative and highly significant correlations ($p<0.001$) with grain yield. The strongest negative correlation with grain yield was observed for ear aspect (r = -0.59). In contrast, plant height and ear height had highly significant positive correlations ($p < 0.001$) with grain yield, with ear height showing the strongest positive correlation (r = 0.53). Northern leaf blight did not show a significant correlation with grain yield.

We observed positive significant relationships between Grey leaf spot and plant aspect with days to 50% anthesis, while husk cover and northern leaf blight showed negative significant relationships, with northern leaf blight having the strongest negative relationship (r = -0.22, $p<0.01$).

Plant height was positively significantly correlated with ear height and husk cover, with ear height showing the strongest positive correlation (r = 0.75). Conversely, ear rot, Grey leaf spot, ear aspect, and plant aspect all had negative but significant correlations with plant height, with plant aspect showing the strongest negative correlation (r = -0.39).

Ear height was positively significantly correlated with husk cover (r = 0.41, $p<0.001$) but showed negative and significant relationships with ear rot, Grey leaf spot, and ear aspect, with ear aspect exhibiting the strongest negative correlation (r = -0.34).

Husk cover was negatively significantly correlated with ear rot (r = -0.23, $p<0.01$) and Grey leaf spot (r = -0.42, $p<0.001$). We observed positive significant relationships between ear rot and Grey leaf spot, ear aspect, and plant aspect, with the strongest relationship being with ear aspect (r = 0.38, $p<0.001$).

Grey leaf spot was positively significantly correlated with ear aspect (r = 0.23) and plant aspect (r = 0.18), while ear aspect was positively significantly correlated with plant aspect (r = 0.51, $p<0.001$).

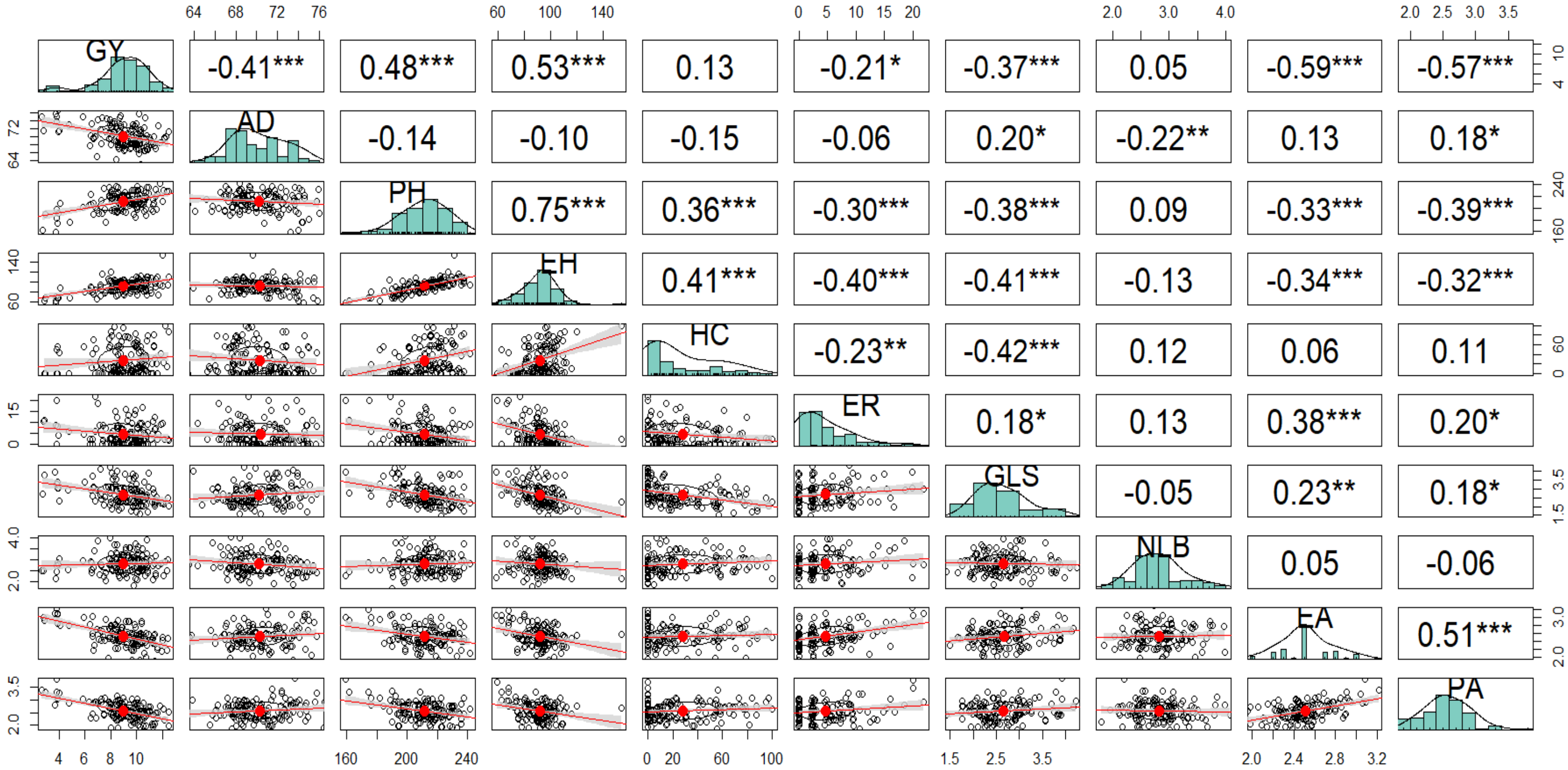

Figure 4. Phenotypic correlations between grain yield and yield related traits at Mabanga. *, **, ***: Significant at *p*<0.05, *p*<0.01, and *p*<0.001 respectively. GY, grain yield; AD, days to 50% anthesis; PH, plant height; EH, ear height; HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect.

4.2.3 Phenotypic correlations at Shikusa.

Figure 5 shows that day to 50% anthesis, ear rot, Grey leaf spot disease (GLS), ear aspect, and plant aspect had highly significant negative correlations ($p<0.001$) with grain yield. The strongest negative correlation was observed for ear aspect, with a coefficient of r = -0.62. In contrast, plant height, ear height, and husk cover exhibited highly significant positive correlations ($p<0.001$) with grain yield, with ear height showing the strongest positive correlation (r = 0.63). Northern leaf blight did not show a significant correlation with grain yield.

The relationship between days to 50% anthesis and other studied traits was positively significant for ear rot, Grey leaf spot, ear aspect, and plant aspect, with ear aspect showing the strongest positive correlation (r = 0.31). In contrast, plant height, husk cover, and Northern leaf blight exhibited negative significant correlations with days to 50% anthesis, with plant height showing the strongest negative correlation (r = -0.29).

We observed positive significant relationships between plant height and both ear height and, with the strongest relationship found between plant height and ear height (r = 0.80). Conversely, negative significant correlations were recorded between plant height and ear rot, Grey leaf spot, ear aspect, and plant aspect, with plant aspect showing the strongest negative relationship (r = -0.53).

Ear height was positively significantly related to husk cover (r = 0.28, $p<0.01$) but negatively significantly correlated to ear rot, Grey leaf spot, ear aspect, and plant aspect, with plant aspect showing the strongest negative relationship (r = -0.47). Husk cover showed a positive significant correlation with both ear aspect and plant aspect.

Ear rot showed positive significant correlations with ear aspect, and plant aspect, with ear aspect having the strongest correlation (r = 0.47, *p*<0.001). GLS had positive significant relationships with both ear aspect and plant aspect, with plant aspect showing the strongest correlation (r = 0.31). Plant aspect had a positive significant correlation with ear aspect (r = 0.58, *p*<0.001).

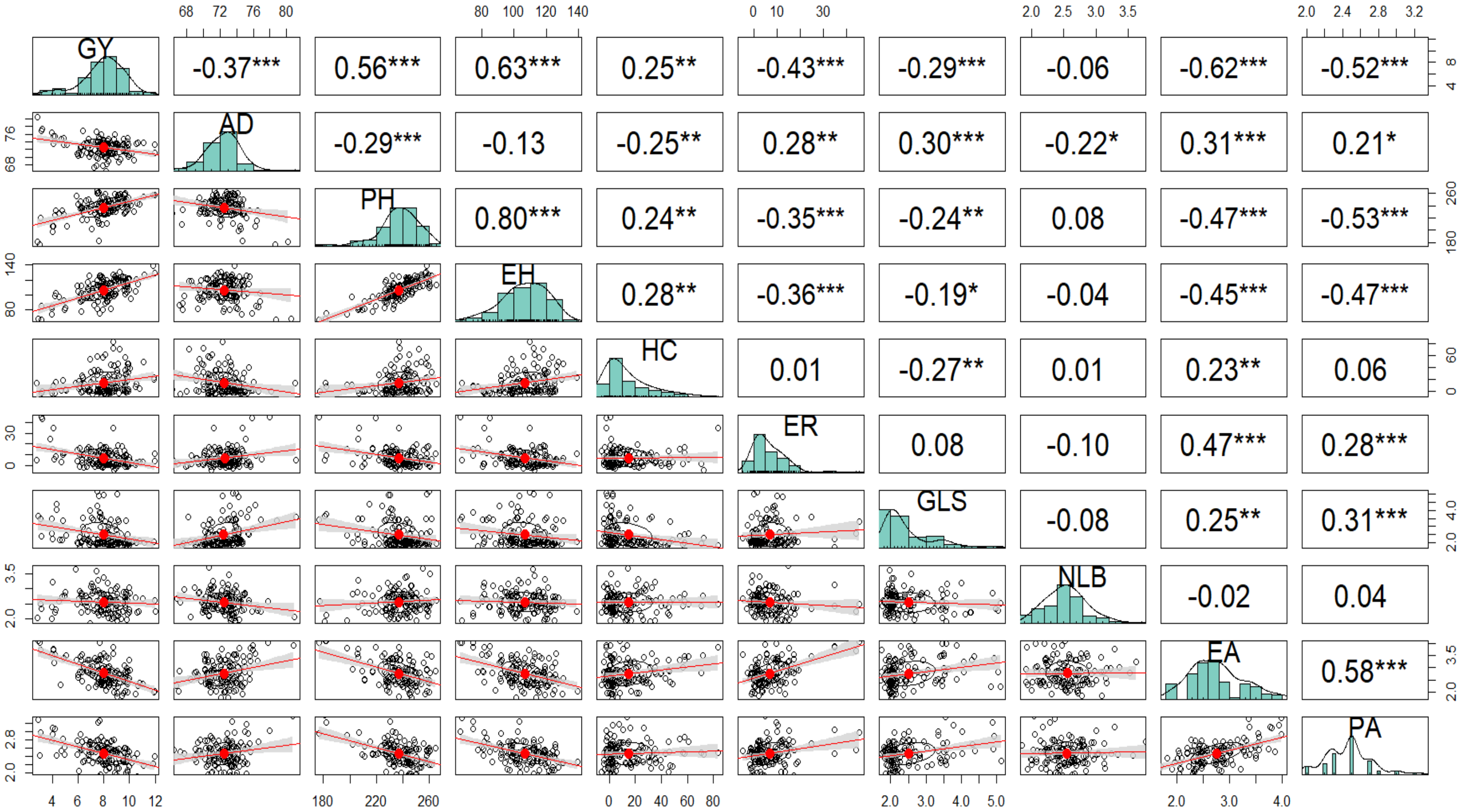

Figure 5. Phenotypic correlations between grain yield and yield related traits at Shikusa.*, **, ***: Significant at *p*<0.05, *p*<0.01, and *p*<0.001 respectively. GY, grain yield; AD, days to 50% anthesis; PH, plant height; EH, ear height; HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect.

4.2.4 Phenotypic correlations across testing locations.

Across the test locations (Figure 6), several significant correlations were observed between grain yield and key agronomic traits. Grain yield showed strong and highly significant negative correlations ($p < 0.001$) with days to 50% anthesis, ear rot, Grey Leaf Spot, ear aspect, and plant aspect. The most pronounced negative correlation was with ear aspect (r = –0.70, $p < 0.001$).

Conversely, grain yield was positively and significantly correlated ($p < 0.001$) with plant height, ear height, and husk cover. Among these, ear height had the strongest positive association with yield (r = 0.67, $p < 0.001$). Notably, no significant correlation was detected between Northern Leaf Blight and grain yield.

Days to 50% anthesis was positively correlated with ear rot, GLS, ear aspect, and plant aspect, with the strongest correlation found between GLS and anthesis date (r = 0.43). On the other hand, significant negative correlations were found between days to anthesis and plant height, husk cover, and Northern Leaf Blight, with plant height showing the strongest negative correlation (r = –0.21, $p < 0.05$).

In addition, plant height was significantly and positively correlated with both ear height (r = 0.81) and husk cover (r = 0.33). In contrast, plant height was negatively correlated with ear rot, GLS, ear aspect, and plant aspect, with ear rot showing the strongest negative correlation (r = –0.46).

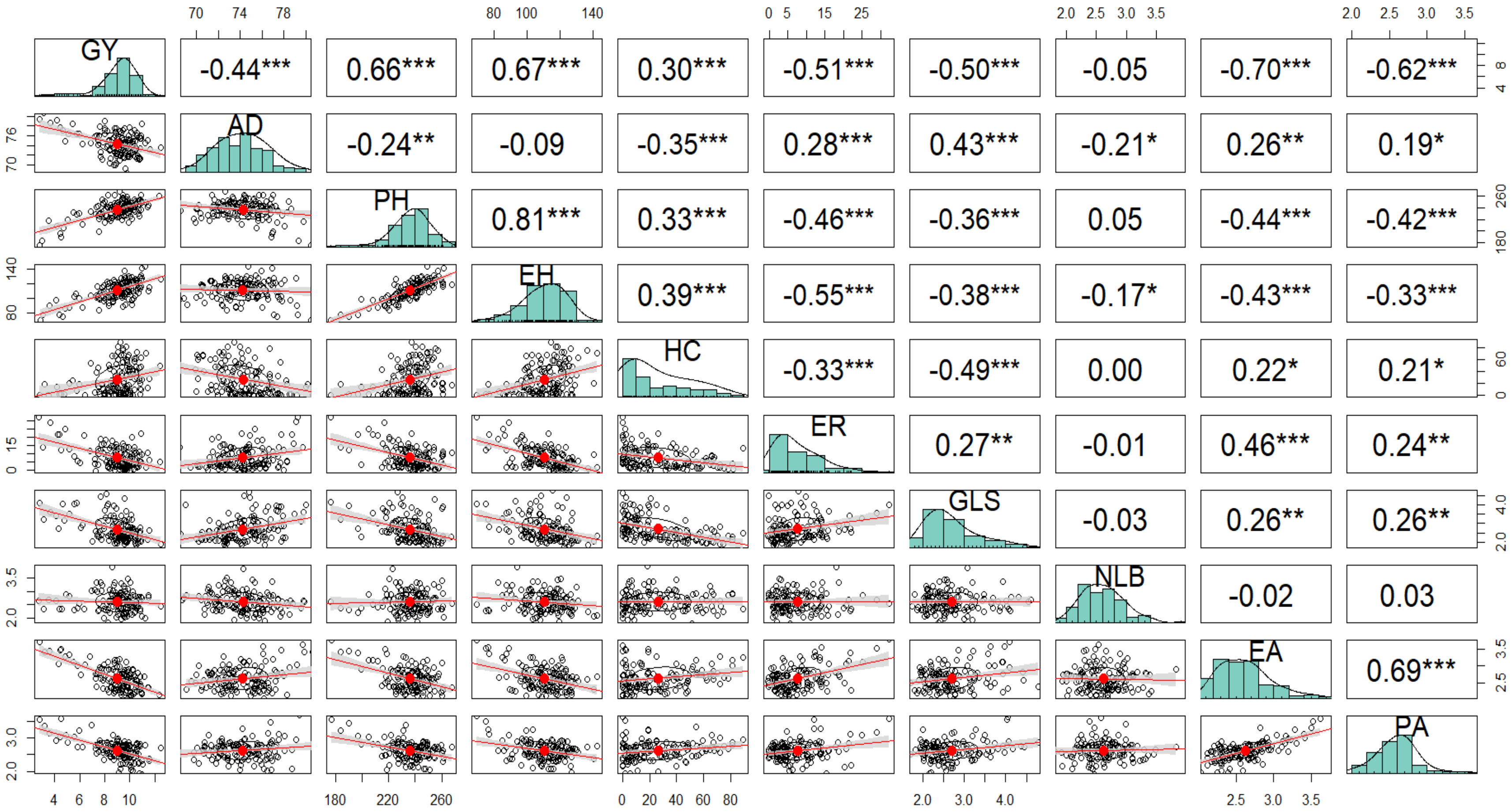

Figure 6. Phenotypic correlations between grain yield and yield related traits across locations. *, **, ***: Significant at $p<0.05$, $p<0.01$, and $p<0.001$ respectively. GY, grain yield; AD, days to 50% anthesis; PH, plant height; EH, ear height; HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect.

4.3 Combining ability analysis and heterotic grouping of the inbred lines.

4.3.1 General and Specific combining ability analysis for grain yield and yield-related traits at Chorlim.

Highly significant differences for the hybrids, GCA ($p<0.01$) as well as SCA ($p<0.05$) for all studied traits (Table 4.9) were recorded. Additive variance was high for days to anthesis, plant height; ear height and husk cover whereas dominance variance was high for grain yield; ear rot; northern leaf blight; ear aspect and plant aspect.

4.3.1.1 General combining ability estimates at Chorlim.

L35 had the highest positive GCA for grain yield at 3.52 ($p<0.05$) whereas L24, L8, L23, and L29 had negative and significant ($p<0.05$) GCA at -3.30, -3.24, -3.16 and –2.79 respectively (Appendix VII). Positive and significant ($p<0.05$) GCA for days to anthesis were recorded for L9 L3 and L65 at 2.25, 1.07 and 0.74 respectively. L16 and L24 had negative but significant ($p<0.05$) GCA for days to anthesis at -2.1 and -0.28 respectively.

Negative and significant GCA for plant height was observed for L8 at -48.05 ($p<0.001$) and L23 at -30.61 ($p<0.001$). Negative and significant GCA values for ear height were recorded for L8 and L23 at -33.44 and -32.67 ($p<0.05$).

Positive and significant GCA for husk cover was observed for L1 at 36.06 while negative GCA was recorded for L50 and L36 at -35.65 and -34.74 ($p<0.05$) respectively. Line L40 and thirty-six others had negative and significant GCA for ear rot. L4 had a positive and significant GCA for Grey leaf spot at this site at 1.3 ($p<0.05$).

Table 4.9 Analysis of variance for combining abilities for grain yield and yield related traits at Chorlim.

		Mean squares									
SOV	*df*	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
REP	1	0.03ns	4.82*	122.33**	822.8***	0.77ns	5.77ns	1.11***	0.15ns	0.002	0.06***
Hybrid	129	7.6***	16.4***	575.35***	473.0***	2043.8***	198.9***	1.49***	0.36***	0.37***	0.37***
GCA_L	64	7.5***	12.8***	769.96***	704.7***	1133.5***	231.9***	1.17***	0.4***	0.41***	0.39**
GCA_T	1	193.5***	991.1***	8220.08***	7903.6***	145443.9***	3221.4***	85.39***	0.03ns	0.41*	1.88**
SCA	64	4.8***	4.78***	261.3***	125.3***	713.5***	118.8***	0.49**	0.31*	0.32***	0.32*
Error	93	0.97	1.99	63.68	46.35	211.51	42.08	0.24	0.19	0.10	0.20
		Proportion of genetic variance (%)									
σ^2_A		3.77	15.55	419.83	464.89	1778.39	107.13	1.33	0.06	0.06	0.06
σ^2_D		7.71	5.57	395.24	157.80	1003.88	153.51	0.49	0.25	0.44	0.25
H^2		0.96	0.95	0.96	0.96	0.96	0.93	0.94	0.76	0.91	0.76

ns, not significant, *, **, ***, significant at $p<0.05$, $p<0.01$, and $p<0.001$ respectively. SOV, source of variation; *df*, degree of freedom; GCA_L, general combining ability of the line; GCA_T, general combining ability of tester; SCA, specific combining ability; σ^2_A, additive genetic variance; σ^2_D, non-additive genetic variance; H^2, broad-sense heritability. GY, grain yield; AD, days to 50% anthesis; PH, plant height; EH, ear height; HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect.

Line L5 exhibited a significant positive general combining ability (GCA) for northern leaf blight, with a value of 1.21 (*p*< 0.001). Additionally, lines L41, L13, and L2 showed positive significant (*p*< 0.05) GCA values of 0.77, 0.74, and 0.65, respectively. For ear aspect, L28 and L24 both had positive GCA values of 0.64 (*p*< 0.05), while L44 demonstrated a negative GCA of -0.64 (*p*< 0.05) for this trait. L8 at 0.93 (*p*<0.01) and L23 and L63 (both at 0.69) had positive GCA for plant aspect. L15 at -0.81 (*p*<0.05) had the only significant GCA for plant aspect.

4.3.1.2 Specific combining ability estimates at Chorlim.

Significant SCA values were observed for studied traits at this site, except for ear height, husk cover, Grey leaf spot and northern leaf blight in (Appendices 8 & 9). Test cross L23×TA had an SCA estimate of 3.96 (*p*<0.05) whereas L23×TB had a -3.96 (*p*<0.05) SCA for grain yield. L8×TA had -3.45 SCA estimate for days to anthesis and a 3.45 SCA for the same trait with tester B (*p*<0.05).

L23×TA, L41×TA and L65×TA had significant SCA for plant height at 27.67, -24.97 and 24.97 (*p*<0.05) respectively and similarly they had significant SCA estimates with tester B at -27.70, 25.04 and -25.01 (*p*<0.05) respectively.

L58×TB and L61×TB had SCA estimates of 0.01 and -9.61 (*p*<0.05) respectively for ear rot. L32×TB and thirty-three other lines crossed with tester B had negative but significant SCA for ear rot. L12×TA had the highest negative SCA for ear rot at -7.51 (*p*<0.01), similarly, twenty-nine other lines had negative but significant SCA estimates for ear rot when crossed with crossed with tester A.

L23 and L29 had contrasting significant SCA estimates for ear aspect at -0.90, -0.93 and 0.90 and 0.93 ($p<0.05$) respectively. L29 had a positive SCA for plant aspect with tester B at 1.09 and a negative SCA estimate with tester A at -1.09 ($p<0.05$).

4.3.2 General and Specific Combining ability analysis for grain yield and yield related traits at Mabanga.

The mean squares for hybrids and general combining ability (GCA) of lines were highly significant across all studied traits ($p<0.001$) (Table 4.10). The mean squares for specific combining ability (SCA) were also highly significant for traits such as grain yield, days to anthesis, plant height, husk cover, ear aspect, and plant aspect. However, SCA means were not significant for ear rot, Grey leaf spot, and northern leaf blight. Additive genetic variance was higher than dominance variance for days to anthesis, plant height, ear height, Grey leaf spot and northern leaf blight but it was low for grain yield, ear rot, ear aspect and plant aspect.

4.3.2.1 General combining ability estimates at Mabanga.

Line L45 had positive and significant ($p<0.05$) GCA for grain yield (2.73) whereas L65, L32, L28 and L8 had negative but significant GCA estimates at -2.97, -2.79 and -2.73 ($p<0.05$) respectively (Appendix X). L65 and L24 at 1.22 and 0.85 ($p<0.05$ & $p<0.01$) respectively had positive GCA for days to anthesis. L26, L3 and L31 at -1.6, -1.29, -0.5 ($p<0.05$) respectively had negative but significant GCA for days to anthesis. L41 at 25.9 and L23 & L10 at -26.28 and -23.63 ($p<0.05$) had significant GCA for plant height.

Table 4.10 Analysis of variance for combining abilities for grain yield and yield related traits at Mabanga.

						Mean squares					
SOV	*df*	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
REP	1	15.01***	12.93***	142.49ns	209.55**	242.5ns	55.75ns	0.41***	0.42ns	0.12***	0.44***
Hybrid	129	7.27***	11.44***	434.45***	307.64***	1613.02***	48.88**	0.6***	0.37***	0.11***	0.22***
GCA_L	64	7.4***	15.26***	530.79***	399.77***	1410.34***	59.93***	0.46***	0.55***	0.14***	0.2***
GCA_T	1	76.35***	213.81***	8221.24***	7789.91***	67011.96***	153.54*	38.29***	0.35ns	0.02ns	0.08ns
SCA	64	6.05***	4.45**	216.44***	98.61ns	793.83*	36.19ns	0.14ns	0.19ns	0.08*	0.23***
Error	93	1.64	2.45	88.31	70.46	470.20	27.28	0.12	0.14	0.05	0.07
					Proportion of genetic variance (%)						
O^2_A		1.63	9.34	291.44	279.44	1095.08	16.96	0.61	0.24	0.04	0.00
O^2_D		8.83	4.01	256.26	56.30	647.26	17.81	0.04	0.10	0.05	0.31
H^2		0.93	0.92	0.93	0.91	0.88	0.72	0.92	0.82	0.78	0.89

ns, not significant, *, **, ***, significant at $p<0.05$, $p<0.01$, and $p<0.001$ respectively. SOV, source of variation; *df*, degree of freedom; GCA_L, general combining ability of line; GCA_T, general combining ability of tester; SCA, specific combining ability; O^2_A, additive genetic variance; O^2_D, non-additive genetic variance; $H^{2,}$ broad-sense heritability. GY, grain yield; AD, days to 50% anthesis; PH, plant height; EH, ear height; HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect.

L47 at 36.86 (p<0.001), L35 at 20.03 (p<0.05) and L23 at -221.79 (p<0.05) had significant GCA for ear height at this site. Lines L55 and L53 at 47.20 and 46.00 (p<0.05) were the only ones with significant GCA for husk cover.

Thirty-nine lines had negative and significant (p<0.01) GCA for ear rot. L14 at 0.92 (p<0.01), L23 at 0.68 (p<0.05) and L27 at -0.70 (p<0.05) had significant GCA for Grey leaf spot. Four lines; L5, L49, L58 and L62 at 0.93, 0.93, 0.81 and 0.81 (p<0.05) had significant GCA for northern leaf blight whereas L28 and L8 at 0.45 and 0.38 (p<0.05) had positive GCA for ear aspect. L45 at -0.4 (p<0.05) had negative GCA for ear aspect. Two lines L10 and L23 had significant GCA for plant aspect at this site at 0.61 (p<0.01) and 0.46 (p<0.05) respectively.

4.3.2.2 Specific combining ability estimates at Mabanga.

L23×TA at 2.81 and L36×TB at 2.80 had the highest SCA with the two testers respectively for grain yield at this site. Similarly, no significant SCA effects were observed for days to anthesis with testcrosses L27×TA at 2.22 and L65×TB having the highest SCA estimates with the two testers respectively (Appendices 11 & 12).

For plant height, both positive and negative but significant SCA estimates were observed for L44 and L65 at 29.48 (p<0.01) and 24.11 (p<0.05) respectively. For ear height, L47 at 19.39 (p<0.01) had contrasting SCA estimates with the two testers.

L16 at -8.96 (p<0.01) had the highest negative SCA for ear rot at this site with tester A. About 25 lines had negative but significant (p<0.01) SCA for ear rot with tester A. Line L28×TB and 36 other lines; all crossed with tester B had negative and significant SCA for ear rot at this site. Only L23×TA at -0.72 (p<0.05) and L23×TB (p<0.05) had significant SCA estimates for plant aspect with the two testers at this site.

4.3.3 General and Specific combining ability analysis for grain yield and yield related traits at Shikusa.

From the analysis of variance for this site (Table 4.13), means for all traits except northern leaf blight were highly significant ($p<0.001$) or ($p<0.01$). Means for line GCA and SCA were also significant or highly significant for all traits except for northern leaf blight, which was not significant. Additive variance was low compared to dominance variance for all traits except for Northern leaf blight.

4.3.3.1 General combining ability estimates at Shikusa.

Significant GCA estimates were shown for all traits in Appendix XIII. L45 and L35 had positive and significant GCA for grain yield at 2.57 and 2.45 ($p<0.05$) respectively whereas L9 and L29 both at -2.53 ($p<0.05$) had negatively significant GCA for grain yield. L65, L7, L64, L9, L56, L3 and L8 at 3.86, 2.32, 1.43, 1.15, 0.71, 0.56 and 0.11 ($p<0.01$) had positive and significant GCA for days to anthesis. L39, L6, L62, L60, L61 and L63 at -5.49, -2.04, -1.75, -0.88, -0.75 and -0.007 had negative but significant GCA for days to anthesis. Significant GCA for plant height was all negative for L8, L23 and L65 at -28.17, -24.43 and -24.02 ($p<0.05$) respectively unlike for ear height where L35 had a significant positive GCA at 25.76 and L33 had a negative significant GCA at -24.52 ($p<0.05$).

Table 4.11 Analysis of variance for combining abilities for grain yield and yield related traits at Shikusa.

		Mean squares									
SOV	*df*	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
REP	1	0.14ns	0.11	52.06ns	19.51	75.94ns	49.67	0.58**	0.5***	0.92**	0.45***
Hybrid	129	5.51***	7.22***	458.61***	353.33***	623.91***	109.64***	1.08***	0.21ns	0.5***	0.13**
GCA_L	64	5.48***	7.81***	572.27***	525.59***	504.28***	115.05***	0.88*	0.24ns	0.53***	0.15**
GCA_T	1	85.47***	197.73***	8697.91***	5964.27***	27289.26***	244.7*	25.54***	0.03ns	1.32**	0.06ns
SCA	64	4.29***	3.65***	216.22***	93.39***	326.91***	102.13***	0.9*	0.17ns	0.46***	0.11*
Error	93	1.61	1.06	40.64	38.32	111.98	40.33	0.57	0.19	0.12	0.08
		Proportion of genetic variance (%)									
O^2_A		1.63	4.77	324.03	347.48	397.03	10.04	0.24	0.05	0.06	0.02
O^2_D		5.37	5.19	351.17	110.15	429.86	123.61	0.65	0.00	0.67	0.08
H^2		0.90	0.95	0.97	0.96	0.94	0.87	0.76	0.33	0.92	0.72

ns, not significant, *, **, ***, significant at $p<0.05$, $p<0.01$, and $p<0.001$ respectively. SOV, Source of variation; *df*, degree of freedom; GCA_L, general combining ability of line; GCA_T, general combining ability of tester; SCA, specific combining ability; O^2_A, additive genetic variance; O^2_D, non-additive genetic variance; H^2 broad -sense heritability. GY, grain yield; AD, days to 50% anthesis; PH, plant height; EH, ear height; HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect.

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At Shikusa, the General Combining Ability (GCA) estimates for ear rot were predominantly negative. Only one line, L28, exhibited a positive GCA estimate of 0.02 ($p<0.05$). In contrast, thirty-six lines had significant negative GCA estimates for ear rot L41, L14, L31 and L25 had positive but significant GCA for Grey leaf spot whereas L62 and L10 at 0.77 ($p<0.01$) and 0.58 ($p<0.05$) respectively had positive and significant GCA for northern leaf blight at this site. L8 and L48 at 0.88 and 0.75 respectively had positive and significant GCA for ear aspect whereas L35 and L45 both at -0.75 had negative but significant GCA for ear aspect ($p<0.05$). For plant aspect L8 & L22 had positive and significant GCA at 0.53 and 0.52 ($p<0.01$) respectively. L10, L9, and L24 also had significant GCA for plant aspect at 0.42, 0.41 and 0.39 ($p<0.05$) respectively.

4.3.3.2 Specific combining ability estimates at Shikusa.

Significant SCA estimates at this site were recorded for days to anthesis, plant height, husk cover, ear rot, northern leaf blight, ear aspect and plant aspect with grain yield, ear height, and Grey leaf spot showing no significant SCA estimates (Appendices XIV& XV).

L65×TA and L2×TB had the highest SCA estimates with the two testers at 2.86 and 1.95 respectively though not significant. Only L65×TA had a significant negative SCA for days to anthesis at -4.03 ($p<0.01$) and a positive SCA was recorded for the same line L65×TB at 4.03 ($p<0.01$). Twenty-nine lines crossed to tester A had negative but significant SCA for ear rot whereas thirty-six lines crossed to tester B had negative but significant SCA for ear rot at this site.

L50×TA had a negative SCA for northern leaf blight at -0.67 ($p<0.05$) and still had same but positive SCA for northern leaf blight with tester B. This was the case with L23×TA which had a negative SCA for ear aspect at -1.05 ($p<0.05$) and a positive SCA in the cross L23×TB at 1.05 ($p<0.05$). L32 and L65 crossed to tester A had significant SCA for plant aspect at 0.5 and -0.49 ($p<0.05$) respectively and with tester B at -0.51 and 0.49 ($p<0.05$) respectively.

4.3.4 General and Specific combining ability analysis for grain yield and yield-related traits across sites.

Analysis of variance across the testing sites (Table 4.12) showed very high significance ($p<0.001$) for the mean squares of the sites for all traits. Similarly mean squares for hybrids and line GCA for all traits were highly significant ($p<0.001$). Except for northern leaf blight, SCA mean squares for all traits were also highly significant ($p<0.001$) across sites. Hybrid by site mean squares were significant for all traits but highly significant ($p<0.001$) for grain yield, anthesis date, ear rot, husk cover and ear aspect. GCA by site mean squares were significant for all traits except for Grey leaf spot and northern leaf blight with very high significance ($p<0.001$) being recorded for days to anthesis, ear rot, husk cover and ear aspect. SCA by site only recorded very high significance in the mean squares for ear rot, with significance recorded for grain yield, husk cover, northern leaf blight as well as ear aspect. Days to anthesis, plant height, ear height, Grey leaf spot and plant aspect were not significant in the across site analysis for SCA by site.

Table 4.12 Analysis of variance for combining abilities for grain yield and yield related traits across three testing sites.

		Mean Squares									
SOV	*df*	GY	AD	PH	EH	ER	HC	GLS	NLB	EA	PA
Site(S)	2	126.77***	2084.71***	39617.11***	40051.22***	1139.32***	31852.31***	9.56***	6.01***	2.65***	5.91***
Rep/S	3	3.72ns	5.14*	102.8ns	308.13***	34.70ns	151.01ns	0.68ns	0.30ns	0.30*	0.39*
Hybrid(H)	129	15.93***	28.46***	1299.06***	993.72***	223.72***	3486.23***	2.31***	0.42***	0.64***	0.43***
GCA$_{L}$	64	16.02***	29.51***	1674.18***	1448.67***	274.62***	2253.18***	1.72***	0.65***	0.72***	0.45***
GCA$_{T}$	1	341.72***	1219.97***	25594.55***	22175.28***	2467.33***	228377.44***	138.17***	0.10ns	0.14ns	0.21ns
SCA	64	10.76***	8.79***	544.36***	207.92***	137.77***	1205.36***	0.78***	0.19ns	0.57***	0.41***
H x S	258	2.21***	3.31***	79.52*	69.04**	66.78***	505.21***	0.41*	0.25**	0.17***	0.14*
GCA$_{L}$ x S	128	2.18**	3.13***	83.07*	84.39***	65.4***	473.66***	0.39ns	0.27**	0.18***	0.14ns
GCA$_{T}$ x S	2	7.81**	96.93***	15.12ns	43.66ns	634.98***	11222.34***	3.96***	0.13ns	0.75***	0.91***
SCA x S	128	2.17**	2.03ns	76.97ns	54.09ns	59.27***	369.32*	0.37ns	0.24*	0.14**	0.13ns
Error	279	1.41	1.83	64.27	51.81	36.98	279.30	0.31	0.18	0.09	0.12
		Proportion of genetic variance (%)									
σ^2_A		2.31	8.76	336.30	350.17	38.30	1016.35	0.68	0.10	0.03	0.01
σ^2_D		6.23	4.64	320.06	104.07	67.20	617.38	0.31	0.01	0.32	0.19
H^2		0.94	0.94	0.98	0.97	0.87	0.93	0.92	0.68	0.90	0.88

ns, not significant, *, **, ***, significant at $p<0.05$, $p<0.01$, and $p<0.001$ respectively. SOV, source of variation; *df*, degree of freedom; GCA$_{L}$, general combining ability of line; GCA$_{T}$, general combining ability of tester; SCA, specific combining ability; σ^2_A, additive genetic variance;σ^2_D, non-additive genetic variance; $H^{2,}$ broad-sense heritability. GY, grain yield; AD, days to 50% anthesis; PH, plant height; EH, ear height; HC, husk over; ER, ear rot; GLS, Grey leaf spot; NLB, northern leaf blight; EA, ear aspect; PA, plant aspect.

4.3.4.1 General combining ability estimates across three testing sites.

Significant GCA estimates across testing sites for grain yield were recorded for L45, L65, L29, L24 and L23. L 45 had the highest positive GCA at 2.66 ($p<0.05$) whereas L65, L29, L24 and L23 had negative but significant GCA at -2.54, -2.50, -2.29 and -2.28 ($p<0.05$) respectively as shown in Appendix XVI. L39, L15 and L33 had negative but significant GCA estimates for days to anthesis at -4.64 ($p<0.01$), -3.79, & -3.66 ($p<0.05$) respectively.

Only two lines had significant GCA estimates for plant height; L8 and L23 at -29.35 & -27.12 ($p<0.05$) respectively. L35 and L47 had positive GCA for ear height at 23.66 and 23.43 ($p<0.05$) respectively whereas L23 and L8 had negative but significant GCA for the same trait at -25.60 and -22.93 ($p<0.05$) respectively. Positive and significant GCA for husk cover was recorded for L55, L1 and L53 at 34.20, 30.23 and 28.70 ($p<0.05$) respectively. L29 was highly significant for the GCA for ear rot at 14.81 ($p<0.01$) whereas lines 25, 23 and 36 at 11.08, 10.61 and 10.29 ($p<0.05$) had significant GCA for this trait across sites.

Only Lines 14 and 31 had significant GCA for Grey leaf spot at 1.16 ($p<0.01$) and 0.78 ($p<0.05$) respectively. For northern leaf blight, very high significance was recorded for L5 at 0.80 ($p<0.001$) while lines 62, 41and 2 at 0.55, 0.47 and 0.47 ($p<0.05$) were positively significant for this trait. L21 had negative but significant GCA for northern leaf blight across sites.

L8, L28 and L48 at 0.62, 0.50 and 0.46 ($p<0.05$) respectively had positive and significant GCA for ear aspect. Line 8 at 0.68 ($p<0.01$), L23 at 0.42 ($p<0.05$) and L35 at -0.41 had significant GCA for plant aspect across sites.

4.3.4.2 Specific combining ability estimates across three testing sites.

Significant SCA estimates of the testcrosses across sites showed significance for all the traits studied in Appendices XVI & XVII. L23×TA, L65×TA, L29×TA and L25×TA showed positive and significant SCA estimates for grain yield whereas L36×TA had a negative but significant SCA for grain yield at -1.91 ($p<0.05$). L23×TB, L65×TB, L29×TB and L25×TB had negative but significant SCA estimates for grain yield whereas L36×TB had a positive SCA for the same trait across sites. L65×TA, L8×TA, L23×TA, L29×TA and L28×TA had negative but significant ($p<0.05$) SCA estimates for days to anthesis however, L49×TA had a positive SCA estimate at 2.04 ($p<0.05$). L49×TB had a negative SCA estimate while L65×TB, L8×TB, L23×TB and L29×TB all had positive but significant SCA estimates for days to anthesis (Appendix 18).

Highly significant SCA estimates were recorded for plant height with both testers. L23×TA, L65×TA, and L24×TA had positive and significant SCA for this trait whereas L44×TA had a negative but significant SCA estimate (Appendix 17). L23×TB, L65×TB and L24×TB had negative but significant SCA estimates while L44×TB had a positive and significant SCA estimate at 15.31($p<0.05$) (Appendix 18). L24×TA, L23×TA, and L65×TA at 9.47, 9.42 and 10.37 ($p<0.05$) respectively had positive SCA estimates for ear height across sites L31×TA had an SCA estimate of -10.18 ($p<0.05$). L24×TB, L23×TB and L63×TB had negative but significant SCA estimates for ear height.

L42×TA had a positive SCA estimate for husk cover at 21.38 ($p<0.05$) and a negative SCA for the same trait at -21.38 ($p<0.05$) with tester B. L23×TA had a highly significant negative SCA for ear rot at -12.19 ($p<0.001$) while L55×TA had the highest positive SCA at 7.37 (*p*<0.05). L23×TB and L55×TB had significant SCA estimates for ear rot at 12.18 and -7.38 (*p*<0.05) respectively. L27×TA and L26×TA had positive SCA estimates for Grey leaf spot at 0.59 and 0.51 (*p*<0.05) while L22×TA had a negative SCA estimate at -0.76 (*p*<0.01). L22×TB at 0.76 (*p*<0.01) was highly significant for Grey leaf spot. L8×TA and L30×TA had positive but significant SCA estimates for northern leaf blight at 0.3 and 0.25 (*p*<0.05) respectively but they were negative and significant with tester B (Appendix 18).

L23×TA and L29×TA had negative and significant SCA for ear aspect across sites at -0.73 and -0.61 (*p*<0.05) respectively but these were positive with tester B. L41×TB on the other hand had a positive but significant at 0.43 (*p*<0.05). For plant aspect, L23×TA, L29×TA and L65×TA had negative SCA but were all positive and significant with tester B. L21×TA had a positive SCA with at 0.41 (*p*<0.05) but L21×TB had a negative SCA. (Appendix XVII).

4.3.5 Heterotic grouping of the inbred lines based on specific combining ability for grain yield.

4.3.5.1 Heterotic grouping of inbred lines at Chorlim

Twenty-nine lines had positive SCA with tester A for grain yield and thus were grouped into the opposite heterotic group B (Table 4.17). These twenty-nine lines also had negative SCA for grain yield with tester B thus grouping into heterotic group B.

Thirty-six inbred lines had positive SCA with tester B thus grouped into the opposite heterotic group A. This set of lines also had negative SCA with tester B thus grouping into the opposite heterotic group A. Thus, heterotic group A had thirty-six inbred lines whereas heterotic group B had twenty-nine inbred lines.

Table 4.13 Heterotic grouping of inbred lines based on SCA estimates for grain yield with the testers at Chorlim.

Line	Tester A SCA	Tester B SCA	Heterotic Group	Line	Tester A SCA	Tester B SCA	Heterotic Group
1	-0.30	0.30	A	36	-2.25	2.25	A
2	-1.11	1.11	A	37	0.41	-0.40	B
3	-1.76	1.76	A	38	-0.01	0.02	A
4	-0.31	0.31	A	39	0.61	-0.61	B
5	0.03	-0.03	B	40	0.79	-0.79	B
6	0.30	-0.30	B	41	-0.50	0.50	A
7	0.21	-0.20	B	42	-0.65	0.65	A
8	2.38	-2.38	B	43	-0.38	0.38	A
9	1.21	-1.21	B	44	-0.97	0.97	A
10	1.54	-1.54	B	45	-0.36	0.36	A
11	1.29	-1.29	B	46	-0.86	0.86	A
12	-0.18	0.18	A	47	-0.80	0.80	A
13	-0.46	0.46	A	48	0.36	-0.36	B
14	-0.34	0.34	A	49	-1.03	1.03	A
15	0.64	-0.64	B	50	-0.07	0.07	A
16	1.11	-1.11	B	51	-0.15	0.15	A
17	-0.82	0.82	A	52	0.46	-0.46	B
18	0.03	-0.03	B	53	-1.02	1.02	A
19	-0.42	0.42	A	54	-1.95	1.96	A
20	-1.16	1.16	A	55	-0.47	0.47	A
21	-0.51	0.51	A	56	0.25	-0.25	B
22	1.27	-1.26	B	57	-0.96	0.96	A
23	3.96*	-3.96*	B	58	0.03	-0.03	B
24	1.05	-1.04	B	59	-0.71	0.72	A
25	1.77	-1.76	B	60	-0.42	0.42	A
26	-0.11	0.12	A	61	0.53	-0.53	B
27	-0.18	0.18	A	62	-1.90	1.90	A
28	0.67	-0.67	B	63	1.40	-1.40	B
29	2.10	-2.10	B	64	-1.96	1.96	A
30	0.59	-0.59	B	65	2.71	-2.71	B
31	-0.56	0.57	A				
32	0.29	-0.29	B				
33	-1.37	1.37	A				
34	0.11	-0.11	B				
35	-1.07	1.07	A				

*, significant at $p<0.05$; SCA_GY; specific combining ability for grain yield.

4.3.5.2 Heterotic grouping of inbred lines at Mabanga.

At Mabanga, twenty-six inbred lines had positive SCA for grain yield with tester A thus grouping into the opposite heterotic group B. These set also had negative SCA with tester B thus were grouped into heterotic group B (Table 4.18). Thirty-nine inbred lines had positive SCA for grain yield with tester B but were also negative with tester A. They were thus grouped into heterotic group A. At this site, there were thus a total of thirty-nine inbred lines grouping into heterotic group A and twenty-six inbred lines were grouped into heterotic group B.

Table 4.14 Heterotic grouping of inbred lines based on SCA estimates for grain yield with the testers at Mabanga.

Line	Tester A SCA_	Tester B SCA_	Heterotic Group
1	1.84	-1.84	B
2	-0.02	0.02	A
3	-0.54	0.54	A
4	0.37	-0.36	B
5	0.12	-0.12	B
6	-0.03	0.03	A
7	-0.05	0.05	A
8	2.71	-2.71	B
9	0.96	-0.95	B
10	1.88	-1.88	B
11	0.52	-0.51	B
12	-1.56	1.57	A
13	-0.39	0.39	A
14	0.17	-0.17	B
15	-0.09	0.10	A
16	1.64	-1.63	B
17	-0.12	0.12	A
18	-0.01	0.01	A
19	-0.21	0.21	A
20	-0.19	0.20	A
21	-0.62	0.62	A
22	1.18	-1.18	B
23	2.81	-2.81	B
24	1.76	-1.75	B
25	2.07	-2.07	B
26	-0.47	0.47	A
27	-2.00	2.00	A
28	1.80	-1.80	B
29	2.35	-2.35	B
30	0.92	-0.92	B
31	-0.07	0.08	A
32	-2.48	2.48	A
33	1.15	-1.15	B
34	-0.44	0.45	A
35	-1.96	1.96	A
36	-2.79	2.80	A
37	0.61	-0.61	B
38	-1.53	1.54	A
39	0.50	-0.50	B
40	-1.57	1.57	A
41	0.22	-0.22	B
42	-0.43	0.43	A
43	-0.21	0.21	A
44	-0.56	0.56	A
45	-0.27	0.27	A
46	-1.27	1.27	A
47	1.38	-1.37	B
48	-0.68	0.69	A
49	-1.40	1.40	A
50	-0.40	0.40	A
51	-1.07	1.07	A
52	-1.56	1.56	A
53	-1.48	1.48	A
54	-1.31	1.31	A
55	-1.04	1.04	A
56	-1.04	1.04	A
57	-1.10	1.10	A
58	-0.32	0.33	A
59	0.18	-0.18	B
60	0.08	-0.07	B
61	-0.34	0.35	A
62	-0.27	0.27	A
63	1.65	-1.65	B
64	0.82	-0.82	B
65	2.31	-2.31	B

SCA_GY; specific combining ability for grain yield.

4.3.5.3 Heterotic grouping of inbred lines at Shikusa.

Thirty inbred lines had positive SCA for grain yield with tester A and thus were grouped into heterotic group B and this was confirmed by their negative SCA with tester B which grouped them equally into heterotic group B except for L27 that had an SCA of 0.00 with tester B (Table 4.20). Thirty-five inbred lines had positive SCA for grain yield with tester B and grouped into the opposite heterotic group A. These thirty-five inbred lines also had positive SCA for grain yield with tester B and thus effectively grouped into heterotic group A.

In total, thirty-five inbred lines grouped into heterotic group A and twenty-nine grouped into heterotic group A. Only a single line did not group effectively into either heterotic group A or B.

Table 4.15 Heterotic grouping of inbred lines based on SCA estimates for grain yield with the testers at Shikusa.

Line	Tester A SCA	Tester B SCA	Heterotic Group	Line	Tester A SCA	Tester B SCA	Heterotic Group
1	-0.10	0.11	A	36	-0.61	0.62	A
2	-1.94	1.95	A	37	0.14	-0.12	B
3	-0.05	0.07	A	38	-0.66	0.67	A
4	-1.12	1.13	A	39	-0.90	0.91	A
5	-1.14	1.16	A	40	0.11	-0.10	B
6	0.57	-0.56	B	41	-0.32	0.34	A
7	0.19	-0.18	B	42	1.50	-1.48	B
8	-0.92	0.94	A	43	0.35	-0.33	B
9	0.62	-0.61	B	44	0.39	-0.38	B
10	1.54	-1.52	B	45	0.88	-0.86	B
11	-0.02	0.04	A	46	-1.88	1.90	A
12	-0.84	0.86	A	47	1.05	-1.04	B
13	-0.42	0.43	A	48	-0.47	0.48	A
14	-0.53	0.55	A	49	-1.65	1.66	A
15	-0.27	0.28	A	50	0.45	-0.44	B
16	2.08	-2.07	B	51	-1.07	1.08	A
17	0.04	-0.03	B	52	0.28	-0.27	B
18	0.82	-0.81	B	53	-0.76	0.77	A
19	0.18	-0.16	B	54	-1.74	1.75	A
20	-0.07	0.08	A	55	-0.14	0.15	A
21	-1.23	1.24	A	56	1.02	-1.01	B
22	-1.00	1.02	A	57	-0.26	0.28	A
23	2.34	-2.33	B	58	-0.85	0.86	A
24	1.66	-1.65	B	59	-1.10	1.12	A
25	1.73	-1.72	B	60	0.03	-0.02	B
26	-0.94	0.95	A	61	-1.05	1.06	A
27	0.02	0.00	-	62	-0.79	0.80	A
28	1.95	-1.94	B	63	0.96	-0.95	B
29	1.66	-1.65	B	64	-0.99	1.01	A
30	1.59	-1.58	B	65	2.86	-2.85	B
31	-1.18	1.19	A				
32	-0.57	0.58	A				
33	-0.10	0.12	A				
34	0.23	-0.22	B				
35	0.87	-0.85	B				

SCA_GY; specific combining ability for grain yield.

4.3.5.4 Heterotic grouping of inbred lines across testing locations.

Across testing locations, heterotic grouping based on SCA for grain yield with the two testers revealed two heterotic groups (Table 4.16). Twenty-five inbred lines had positive SCA with tester A and similarly had negative SCA with tester B, hence grouped into heterotic group B.

Forty inbred lines with positive SCA with tester B were grouped into heterotic group A. Thirty-nine of these inbred lines had negative SCA with tester A were effectively grouped into heterotic group A. Across locations, 60% of the inbred lines grouped into heterotic group A, 38.46% were grouped into heterotic group B and 1.54% of the inbred lines could not be grouped into either of the testers' heterotic groups.

Table 4.16 Heterotic grouping of inbred lines based on SCA estimates for grain yield with the testers across locations.

Lines	SCA Tester A	SCA Tester B	Heterotic group	Lines	SCA Tester A	SCA Tester B	Heterotic group
1	0.47	-0.46	B	36	-1.91*	1.91*	A
2	-1.03	1.04	A	37	0.36	-0.36	B
3	-0.76	0.76	A	38	-0.75	0.76	A
4	-0.34	0.35	A	39	0.07	-0.07	B
5	-0.32	0.32	A	40	-0.24	0.24	A
6	0.28	-0.28	B	41	-0.18	0.19	A
7	0.10	-0.10	B	42	0.16	-0.16	B
8	1.37	-1.36	B	43	-0.08	0.09	A
9	0.94	-0.93	B	44	-0.36	0.36	A
10	1.67	-1.66	B	45	0.07	-0.07	B
11	0.58	-0.57	B	46	-1.33	1.34	A
12	-0.85	0.86	A	47	0.57	-0.56	B
13	-0.41	0.42	A	48	-0.27	0.27	A
14	-0.25	0.26	A	49	-1.37	1.37	A
15	0.07	-0.07	B	50	0.00	0.01	-
16	1.59	-1.58	B	51	-0.79	0.80	A
17	-0.30	0.30	A	52	-0.26	0.26	A
18	0.27	-0.26	B	53	-1.11	1.11	A
19	-0.13	0.14	A	54	-1.68	1.69	A
20	-0.50	0.50	A	55	-0.53	0.53	A
21	-0.78	0.78	A	56	0.11	-0.11	B
22	0.49	-0.49	B	57	-0.82	0.82	A
23	3.02**	-3.02**	B	58	-0.38	0.39	A
24	1.52	-1.52	B	59	-0.54	0.55	A
25	1.89*	-1.88*	B	60	-0.07	0.08	A
26	-0.52	0.53	A	61	-0.30	0.31	A
27	-0.70	0.71	A	62	-0.98	0.99	A
28	1.49	-1.49	B	63	1.33	-1.32	B
29	2.02*	-2.02*	B	64	-0.73	0.74	A
30	1.04	-1.03	B	65	2.64**	-2.63**	B
31	-0.60	0.61	A				
32	-0.92	0.93	A				
33	-0.10	0.11	A				
34	-0.02	0.02	A				
35	-0.71	0.72	A				

**, *, significant at *p*<0.01 and *p*<0.05 respectively; SCA-GY, specific combining ability for grain yield.

CHAPTER FIVE

DISCUSSION

5.1 Hybrid performance, heritability, and phenotypic correlations among studied traits

The development and deployment of maize hybrids that consistently show high and stable performance for grain yield and other agronomic traits across different agro-ecologies are important considerations by breeders addressing the challenge of reducing yields in Kenya and the Sub-Saharan Africa region. This study aimed to determine hybrid performance of the test hybrids across three select testing locations across Western Kenya for grain yield and other agronomic traits. The genotype-by-environment interaction (GEI) variance was highly significant for studied traits except for plant height, and it was smaller in magnitude compared to the genotypic variance. This suggests that the test hybrids exhibited relatively stable performance across all the test environments and is consistent with findings by Engida et al., (2024).

High genotypic variance is an indicator that the genetic potential of the test hybrids played a dominant role in the determination of their performance, which suggests that the test hybrids exhibit significant genetic diversity, which is critical for identifying superior-performing hybrids that can consistently outperform others across test environments. Gebre et al., (2024) and Sorsa et al., (2023) made similar observations when evaluating hybrid performance in sorghum and maize respectively where high genotypic variance was observed. This finding thus points to the idea that genetic selection in this germplasm can be effective since genetic differences among hybrids are the primary drivers of performance, and environmental variation has a lesser influence on the performance of the test hybrids.

Although some hybrids exhibited variation in performance across environments, the overall low magnitude of genotype-by- environment interaction (GEI) variance indicates that most hybrids demonstrated broad adaptability and maintained consistent performance across diverse test sites. However, it is important to note that this study conducted across three environments only, could probably not have that broad dynamism in relation to their climatic conditions and other biotic and abiotic stresses. In more extreme or contrasting environments, the genotype-by-environment interaction may play a more significant role in the performance of the test hybrids and thus submitting these test hybrids to broader testing environments with contrasting characteristics could probably reveal deviations in observed patterns of genotype-by-environment interactions. Adu et al., (2013) and Dehghani et al., (2009) in separate studies found non-significant GEI for grain yield, suggesting stable expression of this trait across multiple environments in tropical maize trials. Findings from this study, together with those of earlier researchers underscore the fact that with a low GEI variance, selection for hybrid varieties can prioritize the use of lines that show consistently superior performance across environments, which reflects broad adaptability and a reliable yield performance.

Robinson et al. (1949) categorized heritability estimates as low (0-30%), moderate (30-60%), and high (>60%). The high heritability results for most of the studied traits suggest that the testing environments had little influence on the expression of these traits. This result agrees with a study by Gichuru (2013), who reported high heritability for grain yield as well as other traits. A moderate heritability was noted at 41% for northern leaf blight, indicating that genotype by environment interaction (GEI) played a significant role in determining the expression of this trait.

Phenotypic correlations were assessed between grain yield and related traits to understand the relationships between yield and these traits in the test germplasm. This analysis is crucial for identifying traits that can be included in the indirect selection criteria to enhance grain yield in breeding programs focusing on exploiting the test germplasm.

The traits analysed in relation to grain yield included days to 50% anthesis, plant height, ear height, husk cover, ear rot, Grey leaf spot, northern leaf blight, ear aspect, and plant aspect. These traits are important as they influence various physiological and morphological aspects of the plant that are linked to yield, either directly or indirectly.

Plant height, ear height, and husk cover had positive and highly significant ($p<0.001$) correlations with grain yield, implying that a positive increase in any of these traits would lead to a positive increase in grain yield. On the other hand, days to 50% anthesis, ear rot, Grey leaf spot, ear aspect, and plant aspect had negative and highly significant ($p<0.001$) correlations with grain yield. Selecting for a decrease in any of these traits will most likely result in a corresponding positive increase in grain yield. Magar et al., (2021) in their study on maize found positive and significant phenotypic correlations between grain yield and traits such as test weight ($r = 0.706$), cob length ($r = 0.671$), cob diameter ($r = 0.573$), and number of rows per cob ($r = 0.539$). The authors concluded that these yield-attributing traits could be used for indirect selection to boost grain production. Results our study are also in agreement with findings by Ali et al., (2017) who in their studies on maize realised significant phenotypic correlations and proposed exploitation in indirect selection criteria. Jemal et al. (2020) also reported positive and significant phenotypic correlations between grain yield and plant height as well as ear height with the highest positive correlation being with ear height.

5.2 Combining ability and heterotic grouping of the inbred lines.

An analysis of variance (ANOVA) performed to ascertain the value of factors affecting the hybrid performance of the test hybrids across environments revealed significant mean squares for sites (S), hybrids (H), and hybrid-by-site interactions (H × S) for grain yield and related traits. This suggests that both germplasm's environment and genetic backgrounds played a critical role in determining the performance of the test hybrids. The significant effect of sites indicates substantial environmental differences across the three testing locations, contributing to differences in the performance of the test hybrids. These differences could include but are not limited to variations in soil types, temperatures, and rainfall that somehow influenced grain yield and related traits.

The significant hybrid effect observed indicates the presence of substantial genetic differences among the hybrids tested, with some hybrids performing better than others due to their inherent genetic potential. Hybrid × Site Interaction (H × S) was also significant, suggesting that the hybrids had differential performance to environmental conditions at different sites. This means that certain hybrids may perform well in specific environments but not in others, indicating the importance of genotype-by-environment interactions in determining hybrid performance. Observed significant site effects emphasize the need to evaluate hybrids across diverse and contrasting environments to identify the most stable and good-performing hybrids for exploitation as potential new cultivars for farmer use. Mushayi et al., (2020) recommended that with significant site effects, METs are required to effectively select for yield stability and adaptability. The significant hybrid and site (H × S) interaction effects imply that hybrid selection should consider both broad adaptability and site-specific performance.

Significant mean squares for the general combining ability of lines (GCA_L) and testers (GCA_T), as well as for specific combining ability (SCA) effects were observed. AbdElAzeem et al., (2022) also reported significant mean squares due to lines (L), testers (T), Lx T with locations and their interaction. These indicate that both additive and non-additive genetic effects were involved in determining grain yield and related traits in this set of germplasm. GCA reflects the average performance of a parent in hybrid combinations, primarily due to additive genetic effects. In the present study, 33 inbred lines were identified to have positive GCA for grain yield and could be exploited for grain yield improvement.

The significance of GCA_L and GCA_T suggests that both the lines and testers contributed significantly to the expression of the traits studied. Thus, additive gene action played a significant role in the expression of grain yield and yield-related traits. These results agree with findings by Ribeiro et al., (2023), who reported a higher consistency of GCA effects of both lines and testers across the testing environments compared to SCA effects. This implies that selection methods based on GCA effects would improve this germplasm for better yields, unlike SCA-based approaches. L15 and L39 had negative and highly significant GCAs for days to 50% anthesis. These possess favourable alleles for reducing maturity in the germplasm. Similarly, L21 had a negative and highly significant GCA for NLB which could be used in introgression of NLB tolerance in elite lines.

SCA represents the interaction between specific parental lines and is associated with non-additive genetic effects (e.g., dominance and epistasis). The significant SCA effects for most traits indicate that non-additive effects also contributed to hybrid performance and these results agree with findings by Abu et al., (2020) and Tabu et al., (2023) who observed significant Tester SCA effects for grain yield in yellow maize. This implies that certain hybrid combinations exhibited better-than-expected performance due to specific genetic interactions between the parents. Tester A had higher SCA effects for grain yield as compared to Tester B in this study and thus considering exploitation of Tester A in development of high yielding yellow maize hybrid could provide good results.

The significance of GCA effects for both lines and testers implies that additive genetic effects are important and selecting parents with high GCA will likely result in improved hybrid performance. This agrees with findings by Manigben et al., (2024), who observed high GCA effects of lines and suggested need of their use as parents in hybrid programs or as testers. The significant SCA effects indicate that heterosis is also important, and breeding programs utilizing this germplasm should focus on exploiting specific parental combinations that show superior performance.

The significant mean squares for GCA_L × S and GCA_T × S interactions for grain yield and most other traits suggest that the general combining abilities of both lines and testers varied across the environments. However, the SCA × S interaction was not significant for most traits, meaning that specific combining ability did not change much across sites. The significant interactions between the general combining abilities of lines and testers with sites (GCA_L × S and GCA_T × S) indicate that the environment also influenced the performance of the parents in hybrid combinations.

Non-significant SCA × S interaction for most traits suggests that non-additive effects (specific hybrid combinations) are relatively stable across environments. This implies that the specific genetic interactions contributing to hybrid performance remained consistent across different sites. This could provide a good platform for breeders seeking to develop hybrids with stable performance across locations utilizing this germplasm.

Line by tester analysis for general combining ability produced significant differences in the GCAs of the inbred lines and the testers for grain yield and yield-related traits. This agrees with the results of other researchers who reported significant GCA estimates (Amegbor et al., 2023; Gatechew & Ngozi, 2020; Shimelis et al., 2019).

For other traits like days to anthesis, plant height, ear height, and disease reactions, a negative GCA is desirable as there is a need for selection to reduce the mean expression of the traits in the hybrids. For instance, lines with negative GCA for days to anthesis would be useful in bringing down the maturity of the hybrids, as suggested by Juma (2012).

Specific combining ability is controlled by the non-additive effect of genes, which are influenced by the environment, cannot be inherited sustainably, and thus is used as a reference when shifting through hybrid combinations (Ju-lin et al., 2018). Results for SCA estimates showed both highly significant and significant positive and negative estimates. These agreed with results by other researchers who reported significant positive and negative SCA estimates in other line-by-tester analyses (Bayisa et al., 2008; Dagne, 2008; Shushay et al., 2013; Kamara et al., 2014; Motamedi et al., 2014; Girma et al., 2015 and Ram et al., 2015). Motamedi et al., (2014) suggested that crosses with significant SCA estimates for grain yield could improve grain yield in a hybrid maize breeding program. Based on the nature of the traits under study, it is possible to exploit testcrosses with significant SCA estimates to improve those traits.

Across testing environments, two major heterotic groups were identified for the germplasm under study. Heterotic group A, from which tester A was oriented, had the majority of the inbred lines at 60%, whereas heterotic group B, from which tester B was oriented, had 38.46% of the inbred lines. This method of heterotic grouping, as described by Gebre (2021), was thus effective in discriminating the inbred lines based on the two testers used. Based on the heterotic grouping, the development of superior hybrids using this germplasm can be done by designing crossing programs between lines across the groups to optimize heterosis. Cheng et al., (2025) in a study on doubled-haploid (DH) maize populations observed that crossing elite lines from different heterotic pools produced superior hybrid with up to 10 % of hybrids from inter-group crosses outperforming the highest-yielding check variety. In a separate study, Maazou et al., (2023) also observed that after SNP-based clustering to classify Pro-vitamin A (PVA) maize inbred lines into distinct heterotic groups followed by crossing of lines from different groups led to both higher PVA and grain yields, highlighting the advantage of inter-heterotic group mating schemes.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The significant and high genotypic variance observed among the yellow maize hybrids underscores their strong genetic potential, with genetic differences among the testcrosses being the primary source of performance variation. The relatively low genotype-by-environment interaction (GEI) variance indicates that most hybrids possess broad adaptation, making them well suited for cultivation across diverse environments. Several testcrosses out yielded the check varieties across the test environments with test cross entry 89 (L45xTA) having the highest grain yield advantage over the checks at 11.6%.

Grain yield and most associated agronomic traits exhibited high heritability across test sites, suggesting that the environments used were representative of the target agro-ecologies for the evaluated germplasm. This also implies a high potential for effective selection and genetic gain.

Correlation analysis revealed that many yield-related traits had a direct influence on grain yield, with ear height showing the strongest positive effect. Negative and highly significant correlation between grain yield and days to 50% anthesis as well as GLS can be included into the indirect selection criteria for enhancing grain yield and overall genetic improvement in this germplasm.

The line × tester analysis used in this study proved effective in dissecting the genetic architecture of the hybrids, revealing both general combining ability (GCA) effects of the parental lines and specific combining ability (SCA) effects of the testcrosses.

Significant GCA and SCA estimates were detected for grain yield and related traits. Thirty-three inbred lines with positive and significant GCA effects for grain yield as well as favourable GCAs for other agronomic traits. These lines possess a combination of favourable alleles and thus are good for use in hybrid breeding programs aimed at improving productivity. High SCA estimates for grain yield were observed between Tester A and the inbred lines as compared to Tester B at 90% of the best performing test crosses on grain yield. Use of Tester A in hybrid breeding programs is most likely to improve on grain yield when working with this germplasm.

6.2 Recommendations

- Testcrosses L45xTA, L47xTA and L35xTB showing equivalent or better performance to the mean of the checks need to be evaluated further in more elaborate multi-environment trials for suitability for release as adaptable and stable superior yielding yellow maize single cross hybrids.
- Based on heterotic grouping of the thirty-three inbred lines with positive GCA for grain yield and favourable GCAs for other related traits, they can be exploited by creating within group single cross parents for three-way hybrid breeding programs as well as in the formation of source populations in new inbred line development using double haploid techniques.
- Molecular approaches such as SNP-based genetic distances, cluster analysis in combination with principal component analysis should be employed to confirm the heterotic grouping of the inbred lines in the study as revealed by the SCAs of their testcrosses.

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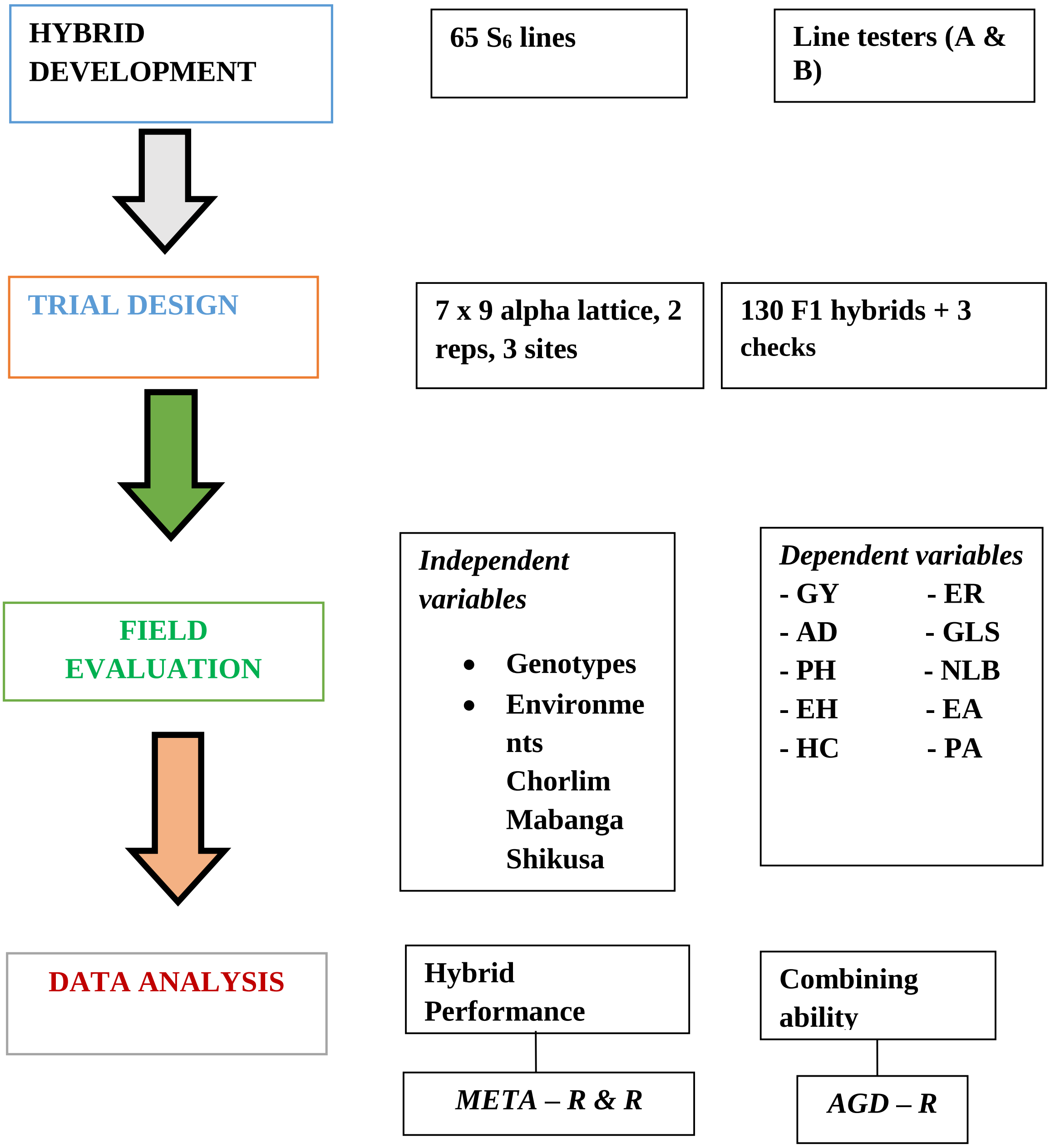
APPENDICES

Appendix I. Conceptual study framework.



Appendix II. Summary of testcrosses and checks in the hybrid evaluation

Entry	Test cross	Pedigree	Entry	Test cross	Pedigree
1	L1×TA	YM21-100-B×TA	41	L21×TA	YM21-187-B×TA
2	L1×TB	YM21-100-B×TB	42	L21×TB	YM21-187-B×TB
3	L2×TA	YM21-112-B×TA	43	L22×TA	YM21-18-B×TA
4	L2×TB	YM21-112-B×TB	44	L22×TB	YM21-18-B×TB
5	L3×TA	YM21-116-B×TA	45	L23×TA	YM21-190-B×TA
6	L3×TB	YM21-116-B×TB	46	L23×TB	YM21-190-B×TB
7	L4×TA	YM21-118-B×TA	47	L24×TA	YM21-198-B×TA
8	L4×TB	YM21-118-B×TB	48	L24×TB	YM21-198-B×TB
9	L5×TA	YM21-123-B×TA	49	L25×TA	YM21-1-B×TA
10	L5×TB	YM21-123-B×TB	50	L25×TB	YM21-1-B×TB
11	L6×TA	YM21-124-B×TA	51	L26×TA	YM21-202-B×TA
12	L6×TB	YM21-124-B×TB	52	L26×TB	YM21-202-B×TB
13	L7×TA	YM21-129-B×TA	53	L27×TA	YM21-203-B×TA
14	L7×TB	YM21-129-B×TB	54	L27×TB	YM21-203-B×TB
15	L8×TA	YM21-12-B×TA	55	L28×TA	YM21-211-B×TA
16	L8×TB	YM21-12-B×TB	56	L28×TB	YM21-211-B×TB
17	L9×TA	YM21-131-B×TA	57	L29×TA	YM21-213-B×TA
18	L9×TB	YM21-131-B×TB	58	L29×TB	YM21-213-B×TB
19	L10×TA	YM21-136-B×TA	59	L30×TA	YM21-223-B×TA
20	L10×TB	YM21-136-B×TB	60	L30×TB	YM21-223-B×TB
21	L11×TA	YM21-140-B×TA	61	L31×TA	YM21-228-B×TA
22	L11×TB	YM21-140-B×TB	62	L31×TB	YM21-228-B×TB
23	L12×TA	YM21-155-B×TA	63	L32×TA	YM21-22-B×TA
24	L12×TB	YM21-155-B×TB	64	L32×TB	YM21-22-B×TB
25	L13×TA	YM21-157-B×TA	65	L33×TA	YM21-231-B×TA
26	L13×TB	YM21-157-B×TB	66	L33×TB	YM21-231-B×TB
27	L14×TA	YM21-166-B×TA	67	L34×TA	YM21-234-B×TA
28	L14×TB	YM21-166-B×TB	68	L34×TB	YM21-234-B×TB
29	L15×TA	YM21-167-B×TA	69	L35×TA	YM21-249-B×TA
30	L15×TB	YM21-167-B×TB	70	L35×TB	YM21-249-B×TB
31	L16×TA	YM21-168-B×TA	71	L36×TA	YM21-256-B×TA
32	L16×TB	YM21-168-B×TB	72	L36×TB	YM21-256-B×TB
33	L17×TA	YM21-16-B×TA	73	L37×TA	YM21-257-B×TA
34	L17×TB	YM21-16-B×TB	74	L37×TB	YM21-257-B×TB
35	L18×TA	YM21-172-B×TA	75	L38×TA	YM21-258-B×TA
36	L18×TB	YM21-172-B×TB	76	L38×TB	YM21-258-B×TB
37	L19×TA	YM21-17-B×TA	77	L39×TA	YM21-265-B×TA
38	L19×TB	YM21-17-B×TB	78	L39×TB	YM21-265-B×TB
39	L20×TA	YM21-186-B×TA	79	L40×TA	YM21-267-B×TA
40	L20×TB	YM21-186-B×TB	80	L40×TB	YM21-267-B×TB

Entry	Test cross	Pedigree	Entry	Test cross	Pedigree
81	L44×TA	YM21-26-B×TA	121	L61×TA	YM21-92-B×TA
82	L44×TB	YM21-26-B×TB	122	L61×TB	YM21-92-B×TB
83	L42×TA	YM21-288-B×TA	123	L62×TA	YM21-95-B×TA
84	L42×TB	YM21-288-B×TB	124	L62×TB	YM21-95-B×TB
85	L43×TA	YM21-297-B×TA	125	L63×TA	YM21-97-B×TA
86	L43×TB	YM21-297-B×TB	126	L63×TB	YM21-97-B×TB
87	L44×TA	YM21-36-B×TA	127	L64×TA	YM22-15×TA-B
88	L44×TB	YM21-36-B×TB	128	L64×TB	YM22-15×TB-B
89	L45×TA	YM21-3-B×TA	129	L65×TA	YM22-3×TA-B
90	L45×TB	YM21-3-B×TB	130	L65×TB	YM22-3×TB-B
91	L46×TA	YM21-42-B×TA	131	YM020-5×TA	CHECK 1
92	L46×TB	YM21-42-B×TB	132	YM020-9×TA	CHECK 2
93	L47×TA	YM21-47-B×TA	133	WY21	CHECK 3
94	L47×TB	YM21-47-B×TB			
95	L48×TA	YM21-48-B×TA			
96	L48×TB	YM21-48-B×TB			
97	L49×TA	YM21-50-B×TA			
98	L49×TB	YM21-50-B×TB			
99	L50×TA	YM21-52-B×TA			
100	L50×TB	YM21-52-B×TB			
101	L55×TA	YM21-54-B×TA			
102	L55×TB	YM21-54-B×TB			
103	L52×TA	YM21-5-B×TA			
104	L52×TB	YM21-5-B×TB			
105	L53×TA	YM21-61-B×TA			
106	L53×TB	YM21-61-B×TB			
107	L54×TA	YM21-62-B×TA			
108	L54×TB	YM21-62-B×TB			
109	L55×TA	YM21-68-B×TA			
110	L55×TB	YM21-68-B×TB			
111	L55×TA	YM21-69-B×TA			
112	L55×TB	YM21-69-B×TB			
113	L57×TA	YM21-73-B×TA			
114	L57×TB	YM21-73-B×TB			
115	L58×TA	YM21-81-B×TA			
116	L58×TB	YM21-81-B×TB			
117	L59×TA	YM21-85-B×TA			
118	L59×TB	YM21-85-B×TB			
119	L60×TA	YM21-91-B×TA			
120	L60×TB	YM21-91-B×TB			

Appendix III. Mean performance of testcrosses for grain yield and yield related traits at Chorlim

Entry	Testcross	GY *T/Ha*	AD *#days*	PH *cm*	EH *cm*	HC *%*	ER *%*	GLS *(1-5)*	NLB *(1-5)*	ER *(1-5)*	PA *(1-5)*
1	L1xTA	11.0	78	264.2	134.5	90.9	1.3	2.0	2.1	3.0	3.0
2	L1xTB	9.8	82	244.0	116.8	55.1	29.6	4.0	2.0	2.8	3.0
3	L2xTA	10.2	77	257.7	132.2	11.9	4.3	2.0	3.0	2.0	2.5
4	L2xTB	10.7	79	253.8	105.9	8.1	1.0	3.0	3.1	2.5	2.0
5	L3xTA	9.5	80	287.1	161.1	43.3	-1.0	2.0	2.9	3.0	3.0
6	L3xTB	11.2	82	265.4	131.3	8.2	-1.4	4.0	2.1	2.5	2.5
7	L4xTA	12.1	79	282.5	158.8	86.3	10.8	2.0	2.4	2.8	3.0
8	L4xTB	11.0	83	261.1	137.2	-2.3	7.4	3.5	2.5	2.3	2.5
9	L5xTA	10.8	77	270.8	127.2	35.9	22.9	1.5	3.2	2.7	2.5
10	L5xTB	9.0	81	249.2	114.0	47.8	33.1	3.0	4.1	2.8	2.5
11	L6xTA	11.2	75	271.6	139.5	92.8	4.4	2.0	2.7	3.0	3.0
12	L6xTB	8.8	82	268.0	140.7	13.5	22.3	3.5	2.1	2.7	3.0
13	L7xTA	10.7	79	274.6	141.5	58.7	2.3	2.5	2.1	2.3	3.0
14	L7xTB	8.5	84	261.3	126.6	56.9	11.6	4.5	2.1	2.5	3.0
15	L8xTA	10.0	74	227.6	117.3	68.6	9.2	3.0	2.8	3.0	3.5
16	L8xTB	3.4	85	197.1	82.6	-2.4	16.8	4.5	1.9	3.5	4.0
17	L9xTA	10.9	80	273.2	146.9	82.6	4.9	2.0	2.5	2.8	3.0
18	L9xTB	6.7	85	265.7	127.6	1.8	13.6	4.5	1.8	3.3	3.0
19	L10xTA	11.2	75	252.5	124.5	84.9	1.2	2.5	2.5	2.8	3.0
20	L10xTB	6.4	81	234.3	106.4	5.3	21.0	4.5	3.0	2.5	2.5
21	L11xTA	12.6	81	249.2	118.7	48.2	12.1	2.5	2.1	2.3	3.0
22	L11xTB	8.2	84	235.3	111.2	2.5	23.8	3.0	2.1	3.0	3.0
23	L12xTA	12.0	76	277.5	150.3	92.6	0.9	2.0	2.4	2.5	3.0
24	L12xTB	10.6	83	266.2	140.6	14.6	23.3	3.5	2.5	2.5	2.0
25	L13xTA	9.1	74	268.1	135.6	84.6	2.4	2.5	2.9	2.8	3.0
26	L13xTB	8.3	78	253.4	124.6	7.8	1.4	2.5	3.4	2.2	2.5
27	L14xTA	10.2	80	250.9	138.6	28.3	5.8	3.5	2.0	2.3	3.0
28	L14xTB	9.1	82	261.5	144.8	1.9	2.8	5.0	2.5	2.3	3.0
29	L15xTA	11.1	74	249.3	108.3	21.5	2.6	2.0	3.0	2.0	2.0
30	L15xTB	8.1	79	246.9	110.8	-1.2	9.2	2.5	2.9	2.3	2.0
31	L16xTA	11.4	76	263.0	132.5	56.2	10.5	2.5	2.5	2.5	3.0
32	L16xTB	7.3	80	238.2	102.8	2.2	27.3	3.5	2.0	2.8	2.5
33	L17xTA	11.1	76	273.4	146.0	81.7	4.7	2.0	3.0	3.2	3.0
34	L17xTB	10.9	83	271.0	147.9	38.3	-0.2	2.0	1.9	2.7	2.5
35	L18xTA	10.1	83	258.3	144.4	81.2	2.7	2.0	2.0	2.8	3.0
36	L18xTB	8.2	84	219.2	118.3	14.4	8.7	2.5	2.1	2.7	3.0
37	L19xTA	11.2	79	266.8	147.0	72.7	2.2	3.0	2.0	2.7	3.0
38	L19xTB	10.3	83	251.5	135.2	-0.2	5.0	3.0	2.4	2.0	2.0
39	L20xTA	11.1	78	265.3	150.7	69.5	3.5	2.0	2.1	2.2	2.0
40	L20xTB	11.6	82	247.1	125.4	0.5	9.2	3.0	2.0	1.8	2.5

41	L21xTA	10.2	77	246.7	127.3	100.8	5.2	2.0	2.0	3.0	3.5
42	L21xTB	9.5	82	253.2	133.8	5.2	8.4	3.0	2.1	2.7	2.0
43	L22xTA	11.6	79	265.1	154.8	30.0	5.7	2.0	2.4	2.5	3.0
44	L22xTB	7.3	82	261.0	133.2	6.7	18.6	4.5	2.6	2.7	2.5
45	L23xTA	11.6	78	263.4	117.3	47.7	2.5	3.0	1.9	2.3	3.0
46	L23xTB	1.9	88	196.2	84.1	-0.5	31.6	5.0	2.9	4.0	4.0
47	L24xTA	8.6	76	261.0	127.5	76.7	9.6	2.0	2.0	3.0	3.0
48	L24xTB	4.7	83	214.3	87.5	0.4	42.7	3.0	2.1	3.5	3.5
49	L25xTA	10.1	82	254.8	135.1	67.4	27.0	2.0	2.0	3.0	3.0
50	L25xTB	4.7	85	224.8	137.9	-1.4	31.7	4.0	2.6	3.0	3.0
51	L26xTA	10.8	80	265.1	145.6	79.2	9.3	2.5	2.4	2.8	3.0
52	L26xTB	9.3	82	271.9	153.5	2.5	12.0	3.0	1.9	2.5	2.5
53	L27xTA	12.0	81	262.7	147.1	41.4	3.6	2.5	2.0	2.2	2.5
54	L27xTB	10.6	84	258.9	138.3	-0.3	8.9	2.5	2.4	1.8	2.0
55	L28xTA	9.7	77	255.8	125.6	89.7	7.2	2.5	2.0	2.8	3.0
56	L28xTB	6.6	84	248.6	115.7	0.6	24.2	4.0	3.0	3.7	2.5
57	L29xTA	10.1	78	270.3	136.2	15.1	22.4	2.5	2.1	2.0	2.0
58	L29xTB	4.2	87	234.5	111.1	1.5	34.9	5.0	2.4	3.8	4.0
59	L30xTA	10.0	78	284.9	140.7	68.4	7.9	3.0	2.5	2.5	2.5
60	L30xTB	7.1	83	256.8	129.0	7.6	5.2	4.5	2.1	3.0	3.0
61	L31xTA	11.2	78	276.5	140.4	89.6	3.4	3.0	2.1	2.8	3.0
62	L31xTB	10.6	82	280.9	147.7	50.1	0.1	4.5	3.0	2.5	3.0
63	L32xTA	10.4	77	252.3	128.2	79.3	19.0	2.0	2.9	3.3	3.5
64	L32xTB	8.1	84	268.7	126.3	54.5	11.7	2.0	3.0	2.8	3.0
65	L33xTA	8.9	75	261.8	120.3	32.2	21.5	2.0	2.6	2.2	3.0
66	L33xTB	9.8	78	244.6	104.7	1.3	24.2	3.0	3.1	2.7	2.5
67	L34xTA	11.9	80	275.7	156.2	65.8	8.3	2.0	2.9	2.8	3.0
68	L34xTB	9.9	81	254.2	128.4	7.2	24.8	3.5	2.0	2.2	2.5
69	L35xTA	13.3	81	292.3	168.6	29.4	14.0	2.5	2.1	2.5	2.5
70	L35xTB	13.6	86	269.5	148.6	0.6	9.6	2.0	2.0	2.2	2.0
71	L36xTA	8.4	75	249.0	121.7	4.1	33.1	2.5	2.5	2.8	3.0
72	L36xTB	11.2	80	240.5	115.6	0.5	31.7	3.0	1.9	2.5	2.5
73	L37xTA	11.4	77	258.2	125.9	47.8	5.0	2.0	2.1	2.5	2.5
74	L37xTB	8.9	81	258.4	134.3	2.1	9.8	2.0	3.2	2.0	3.0
75	L38xTA	13.3	76	284.5	146.8	87.7	4.3	2.0	2.5	3.0	3.0
76	L38xTB	11.5	81	278.8	145.0	3.5	26.7	4.0	2.0	2.3	2.5
77	L39xTA	11.6	73	230.3	112.1	65.8	-0.9	3.0	2.5	2.7	3.0
78	L39xTB	8.6	80	252.6	118.6	18.0	5.8	5.0	2.5	1.7	2.5
79	L40xTA	14.0	81	272.5	158.3	63.6	0.8	1.5	2.1	2.3	3.0
80	L40xTB	10.6	83	262.4	152.7	-0.6	2.2	3.0	3.0	2.5	2.5
81	L44xTA	11.2	78	245.5	139.2	98.3	-1.7	2.5	3.2	3.3	3.0
82	L44xTB	10.4	83	283.7	144.8	10.3	7.4	3.5	3.2	1.7	3.0
83	L42xTA	9.7	80	268.7	142.4	72.2	1.3	2.0	2.4	3.0	3.0
84	L42xTB	9.2	84	264.2	135.3	7.4	18.1	3.0	3.6	2.5	2.5
85	L43xTA	12.3	77	269.7	143.0	61.0	3.5	3.0	2.0	2.5	3.5

86	L43xTB	11.3	82	260.6	130.3	11.2	12.2	3.5	2.5	2.3	2.5
87	L44xTA	11.5	78	259.7	154.6	38.5	5.6	2.0	2.4	2.0	3.0
88	L44xTB	11.7	79	263.3	146.9	0.6	12.4	4.0	2.0	2.0	3.0
89	L45xTA	13.1	82	276.6	152.7	86.2	1.2	1.5	1.9	2.5	3.0
90	L45xTB	12.0	83	255.6	128.5	31.8	41.3	3.0	2.1	2.8	2.0
91	L46xTA	8.8	81	268.1	142.6	18.2	1.3	2.5	3.0	2.7	2.5
92	L46xTB	8.8	84	268.1	144.9	-1.5	-1.4	3.5	2.5	2.2	2.5
93	L47xTA	10.3	79	268.1	150.8	65.6	-0.3	2.5	2.1	3.3	3.0
94	L47xTB	10.1	83	262.6	144.2	0.0	12.9	3.5	2.6	2.0	3.0
95	L48xTA	11.1	79	277.0	143.0	82.5	1.9	3.0	2.6	3.0	3.0
96	L48xTB	8.5	82	289.5	141.1	7.3	18.3	4.5	2.0	3.0	3.0
97	L49xTA	10.6	79	262.1	117.4	40.5	15.4	2.5	2.5	2.3	3.0
98	L49xTB	10.9	78	246.9	108.8	12.8	9.4	4.0	2.7	1.8	2.0
99	L50xTA	10.4	77	291.5	149.9	2.1	12.7	3.0	2.9	2.5	3.0
100	L50xTB	8.7	83	274.1	122.4	0.6	25.1	4.0	2.0	2.8	2.5
101	L55xTA	10.3	75	261.4	141.2	47.9	-1.3	2.0	2.9	2.8	2.5
102	L55xTB	8.8	80	258.2	139.6	6.6	12.0	2.0	2.3	2.5	2.5
103	L52xTA	12.2	77	258.4	145.2	63.4	2.8	3.0	2.4	2.0	2.5
104	L52xTB	9.5	80	255.2	133.1	1.5	23.5	4.0	1.9	2.8	2.5
105	L53xTA	11.7	80	288.7	162.5	94.8	2.2	2.0	1.9	2.8	3.0
106	L53xTB	12.0	85	283.3	156.7	20.7	9.2	3.0	2.5	2.7	2.5
107	L54xTA	8.9	77	266.0	140.0	80.7	0.9	2.0	2.5	3.0	3.0
108	L54xTB	11.0	81	267.1	130.9	59.0	9.6	3.5	3.0	2.8	2.0
109	L55xTA	9.9	81	259.2	139.1	83.0	2.4	3.5	2.0	3.0	3.0
110	L55xTB	9.0	83	255.5	122.5	31.5	3.1	4.0	2.5	2.5	3.0
111	L55xTA	11.6	78	248.3	118.9	86.0	19.4	2.0	2.0	3.3	3.0
112	L55xTB	9.3	81	229.4	109.7	21.7	22.6	4.0	2.9	2.8	2.5
113	L57xTA	10.7	82	276.2	155.8	99.0	1.9	3.0	2.5	2.0	3.0
114	L57xTB	10.8	84	269.1	154.1	10.9	2.1	4.0	2.4	2.0	3.0
115	L58xTA	10.5	81	272.2	153.9	24.6	2.8	3.0	3.0	2.7	3.0
116	L58xTB	8.6	80	254.2	136.8	6.7	10.3	3.5	2.5	2.5	3.0
117	L59xTA	9.3	79	263.1	139.7	80.7	1.2	2.5	1.5	3.0	2.5
118	L59xTB	9.0	83	259.2	125.2	3.1	29.9	3.0	2.1	3.0	3.0
119	L60xTA	12.0	76	292.1	135.9	20.9	24.9	2.5	2.1	2.5	2.0
120	L60xTB	11.1	77	275.0	128.0	28.0	4.5	4.0	1.9	2.5	3.0
121	L61xTA	12.2	76	298.0	143.9	34.4	13.9	2.5	2.5	2.0	3.0
122	L61xTB	9.3	77	262.4	130.6	28.3	1.9	4.0	2.0	2.2	3.0
123	L62xTA	8.4	79	284.0	139.6	25.0	15.1	2.5	3.0	2.8	3.5
124	L62xTB	10.4	80	270.1	126.2	18.6	1.9	3.5	1.9	2.2	3.0
125	L63xTA	11.3	77	264.6	143.2	47.0	-0.8	2.5	2.5	2.2	3.0
126	L63xTB	6.8	84	253.9	122.1	13.2	2.7	3.5	2.0	2.5	4.0
127	L64xTA	8.8	77	264.4	138.3	74.3	21.7	2.5	2.9	3.5	2.5
128	L64xTB	10.9	82	255.0	135.8	20.0	8.0	3.0	2.0	2.5	2.5
129	L65xTA	11.0	77	266.9	128.5	73.3	7.0	2.5	2.0	2.7	3.0
130	L65xTB	3.8	85	205.6	98.1	44.7	26.3	3.5	2.4	3.5	3.5

131	YM020-5xTA	12.3	79	268.2	130.2	30.4	16.2	2.0	2.0	2.8	3.0
132	YM020-9xTA	14.3	80	271.3	133.1	66.9	10.2	2.0	2.6	2.5	3.0
133	WY21	13.9	78	272.3	138.4	9.9	19.0	3.0	2.6	2.0	2.0

Appendix IV. Mean performance of testcrosses for grain yield and yield related traits at Mabanga.

Entry	Testcross	GY T/Ha	AD #days	PH cm	EH cm	HC %	ER %	GLS (1-5)	NLB (1-5)	ER (1-5)	PA
1	L1xTA	11.4	67	221.0	98.5	55.0	7.2	2.0	3.3	2.5	2.5
2	L1xTB	6.6	70	208.0	80.1	70.5	0.0	3.0	2.5	2.3	2.8
3	L2xTA	10.1	66	214.5	94.9	17.7	7.7	2.3	3.5	2.3	2.3
4	L2xTB	9.0	67	194.6	76.7	5.0	2.2	2.9	3.3	2.5	2.5
5	L3xTA	10.1	68	229.7	103.5	43.9	0.0	2.0	3.3	2.5	2.8
6	L3xTB	10.1	70	219.8	95.4	9.6	2.7	2.7	3.3	2.3	2.6
7	L4xTA	12.4	72	229.4	110.7	87.5	2.1	2.0	3.0	2.5	2.5
8	L4xTB	10.6	74	216.1	96.7	9.4	2.2	2.5	2.5	2.2	2.3
9	L5xTA	9.8	69	212.0	90.4	9.8	13.9	2.3	3.8	2.7	2.2
10	L5xTB	8.5	72	192.6	73.2	0.0	8.7	3.5	3.8	2.7	3.3
11	L6xTA	9.1	68	215.3	96.7	75.7	4.9	2.3	3.5	2.8	2.8
12	L6xTB	8.1	71	223.3	97.6	15.0	3.0	3.0	3.3	2.5	2.0
13	L7xTA	10.7	71	235.9	109.6	37.3	0.0	2.5	3.3	2.3	2.0
14	L7xTB	9.7	74	221.6	96.7	0.0	0.0	3.8	3.0	2.5	2.5
15	L8xTA	9.5	68	205.2	83.0	73.8	4.8	2.5	3.0	2.8	2.8
16	L8xTB	2.9	72	190.2	68.2	0.0	10.4	3.8	2.5	3.0	3.3
17	L9xTA	8.9	68	222.3	103.6	65.6	6.9	2.6	3.3	2.8	2.8
18	L9xTB	5.9	74	201.0	79.8	55.0	4.6	3.3	3.0	3.0	3.1
19	L10xTA	8.8	69	200.4	82.0	25.8	2.2	2.3	2.5	2.5	2.9
20	L10xTB	4.0	71	174.6	67.9	0.0	20.0	3.1	2.8	3.2	3.4
21	L11xTA	10.5	72	212.2	89.7	26.2	16.8	2.0	3.5	2.8	2.6
22	L11xTB	8.3	74	194.8	84.1	2.5	15.0	3.8	2.8	2.7	2.5
23	L12xTA	10.3	70	222.2	98.3	56.6	2.2	1.5	2.5	2.3	2.5
24	L12xTB	12.4	71	228.4	93.8	15.0	2.2	2.5	2.5	2.2	2.0
25	L13xTA	10.0	68	220.6	101.2	65.0	2.5	2.6	3.0	2.5	2.4
26	L13xTB	9.7	69	208.9	85.5	7.7	0.0	3.3	2.5	2.3	2.5
27	L14xTA	8.8	71	196.8	101.1	9.5	0.0	3.0	2.5	2.5	2.3
28	L14xTB	7.3	69	192.0	90.0	0.0	8.8	4.2	2.8	2.7	3.0
29	L15xTA	10.1	66	202.7	75.3	5.0	2.3	2.3	2.8	2.5	2.3
30	L15xTB	9.1	67	193.5	74.9	0.0	2.3	3.0	3.0	2.5	2.5
31	L16xTA	11.1	69	197.5	84.0	20.0	2.4	2.2	3.0	2.5	2.7
32	L16xTB	6.7	69	188.8	76.6	0.0	21.9	3.0	2.8	3.0	3.0
33	L17xTA	10.9	69	225.2	104.7	69.1	0.0	1.7	2.5	2.5	2.5
34	L17xTB	10.0	70	200.6	95.1	9.5	0.0	2.5	2.3	2.5	2.8
35	L18xTA	8.7	75	211.5	99.8	40.5	0.0	2.3	2.5	2.5	3.0
36	L18xTB	7.6	74	176.0	79.8	19.5	0.0	2.5	2.5	3.0	3.0
37	L19xTA	10.0	68	201.3	100.8	53.2	0.0	2.1	3.0	2.5	2.5
38	L19xTB	9.4	69	222.6	95.1	0.0	4.8	2.5	2.3	2.3	2.6
39	L20xTA	10.3	69	222.1	111.9	23.8	2.4	2.0	2.5	2.3	2.8
40	L20xTB	9.6	70	207.3	93.3	5.4	5.3	2.8	2.8	2.2	2.2
41	L21xTA	9.6	68	211.9	95.2	39.1	4.8	2.0	2.5	2.5	3.0
42	L21xTB	9.8	73	189.9	86.3	5.0	0.0	2.5	1.8	2.2	2.2
43	L22xTA	11.5	68	224.4	110.3	21.9	2.3	2.5	2.3	2.3	2.5

44	L22xTB	8.0	69	196.7	86.7	0.0	2.3	4.2	2.8	2.7	2.8
45	L23xTA	10.5	70	210.7	81.2	30.6	6.5	2.8	3.3	2.5	2.3
46	L23xTB	3.8	74	159.3	58.8	0.0	20.0	4.0	2.3	3.0	3.8
47	L24xTA	9.4	68	211.5	92.9	76.2	3.0	2.2	3.0	2.5	2.6
48	L24xTB	4.8	74	176.3	67.9	0.0	5.9	3.0	2.5	2.8	2.8
49	L25xTA	9.2	70	213.4	95.3	31.1	10.8	2.3	2.3	2.5	2.5
50	L25xTB	4.0	76	191.9	67.8	42.9	8.4	3.0	2.8	2.8	3.0
51	L26xTA	11.4	68	231.8	105.0	58.4	7.3	2.3	2.3	2.5	2.5
52	L26xTB	11.2	69	205.5	108.6	0.0	4.6	2.8	2.3	2.3	2.0
53	L27xTA	8.7	74	207.1	93.5	18.6	0.0	1.8	3.0	2.3	2.8
54	L27xTB	11.6	72	198.5	74.9	0.0	4.6	2.2	2.8	2.2	2.3
55	L28xTA	8.5	68	215.7	89.9	79.1	12.2	3.0	2.5	3.0	2.5
56	L28xTB	3.8	75	181.8	62.6	50.0	0.0	3.3	2.5	3.0	3.0
57	L29xTA	9.6	68	230.0	104.3	2.4	9.6	2.0	2.8	2.5	2.0
58	L29xTB	3.8	74	197.9	71.0	0.0	8.8	3.3	2.8	3.0	2.8
59	L30xTA	9.4	69	218.6	94.5	23.3	4.8	2.3	3.5	2.8	2.3
60	L30xTB	6.5	73	206.7	88.9	13.4	2.4	3.8	2.5	2.5	2.4
61	L31xTA	10.0	69	229.8	97.2	61.9	0.0	2.7	2.8	2.5	2.8
62	L31xTB	9.0	71	227.5	104.5	12.3	0.0	3.8	2.5	2.5	2.4
63	L32xTA	4.0	72	208.6	88.8	56.3	4.2	2.3	3.0	2.7	3.3
64	L32xTB	7.9	72	218.3	83.1	58.1	0.0	3.0	3.0	2.5	2.7
65	L33xTA	10.3	64	206.9	87.4	13.4	9.6	2.1	2.8	2.5	2.5
66	L33xTB	6.9	66	196.2	66.2	14.7	18.6	3.0	3.8	2.8	2.9
67	L34xTA	10.1	68	229.6	109.6	67.9	2.3	2.3	2.5	2.5	2.7
68	L34xTB	10.0	69	198.3	90.9	0.0	7.5	3.2	2.0	2.3	2.8
69	L35xTA	7.4	74	233.9	116.0	10.9	2.2	2.0	2.3	2.5	2.5
70	L35xTB	10.2	76	232.6	107.8	5.9	2.5	2.5	2.5	2.0	2.0
71	L36xTA	6.8	70	201.5	83.5	52.5	5.9	2.3	3.5	2.3	2.4
72	L36xTB	11.2	68	194.1	78.1	0.0	10.7	3.0	3.0	2.5	1.9
73	L37xTA	11.3	68	215.6	98.7	81.7	0.0	2.3	2.8	2.3	2.0
74	L37xTB	8.9	70	219.3	89.7	2.7	7.2	2.5	2.3	2.5	2.4
75	L38xTA	6.5	68	223.9	90.0	42.4	0.0	2.5	2.8	2.5	2.3
76	L38xTB	8.4	72	218.2	90.4	0.0	7.4	2.9	3.0	2.5	2.3
77	L39xTA	10.6	66	194.3	83.4	35.7	2.3	2.5	2.8	2.5	2.0
78	L39xTB	8.5	64	193.9	73.6	0.0	0.0	3.9	2.8	2.5	3.0
79	L40xTA	7.9	74	220.6	102.7	53.9	2.4	2.2	2.8	2.0	2.8
80	L40xTB	10.0	74	211.8	90.2	11.9	2.3	2.9	2.3	2.3	2.5
81	L44xTA	10.0	69	237.5	107.6	83.4	0.0	1.7	3.0	2.5	3.0
82	L44xTB	8.4	72	237.3	101.1	46.5	2.4	3.0	3.8	2.8	2.5
83	L42xTA	8.4	69	213.5	97.2	96.7	2.5	2.0	3.3	2.5	3.0
84	L42xTB	8.2	70	197.1	81.5	6.7	0.0	2.6	3.0	2.5	2.8
85	L43xTA	10.3	68	217.3	103.6	27.5	0.0	2.5	2.8	2.5	2.2
86	L43xTB	9.6	70	208.8	89.5	0.0	5.6	3.0	3.3	2.3	2.4
87	L44xTA	10.8	68	188.4	104.0	17.7	4.4	2.2	2.8	2.5	2.5
88	L44xTB	10.9	70	234.7	110.6	2.7	9.3	3.8	2.5	2.5	2.5
89	L45xTA	11.9	69	241.6	94.1	40.5	9.1	2.1	2.8	2.2	2.7
90	L45xTB	11.4	71	208.5	89.2	31.2	12.4	2.2	2.8	2.0	2.1
91	L46xTA	7.3	72	213.5	93.7	16.7	0.0	2.5	2.8	2.5	3.0
92	L46xTB	8.7	73	211.5	92.6	30.0	0.0	3.0	3.3	2.5	2.3
93	L47xTA	12.1	69	231.2	154.2	100.0	2.4	2.3	2.3	2.5	2.7
94	L47xTB	8.3	74	215.9	103.2	6.5	0.0	3.1	2.8	2.2	2.5

95	L48xTA	7.9	70	222.5	105.8	72.9	2.7	2.8	2.8	3.0	3.0
96	L48xTB	8.1	74	229.9	98.4	0.0	2.7	3.8	2.5	2.7	2.5
97	L49xTA	9.1	68	212.7	80.8	22.4	16.0	2.5	3.5	2.2	3.0
98	L49xTB	10.8	67	198.8	74.4	7.3	5.3	3.0	4.0	2.2	2.5
99	L50xTA	8.5	72	235.7	95.1	0.0	0.0	2.3	3.0	2.2	2.2
100	L50xTB	8.2	72	223.3	90.6	11.9	5.8	3.6	2.5	2.5	2.3
101	L55xTA	8.7	68	200.9	96.2	56.6	7.2	2.2	2.8	2.5	2.6
102	L55xTB	9.8	72	205.5	98.6	0.0	0.0	2.3	3.0	2.3	2.2
103	L52xTA	8.6	68	216.8	100.0	40.0	0.0	2.3	2.5	2.5	2.3
104	L52xTB	10.6	69	206.8	82.0	0.0	0.0	3.3	2.3	2.5	2.5
105	L53xTA	8.0	72	227.4	120.5	87.5	0.0	1.8	2.8	2.5	2.7
106	L53xTB	9.8	71	230.2	95.4	61.2	15.4	2.9	3.0	2.8	2.8
107	L54xTA	8.8	73	218.3	99.7	18.3	0.0	2.0	2.3	2.7	2.8
108	L54xTB	10.3	71	214.3	92.7	47.4	9.4	2.8	3.0	2.5	2.2
109	L55xTA	8.9	69	216.9	96.0	95.0	2.8	2.5	2.8	2.7	3.0
110	L55xTB	9.9	73	184.5	83.0	56.1	2.5	3.7	3.0	2.3	2.8
111	L55xTA	8.6	68	210.5	93.8	19.1	0.0	2.5	3.0	2.5	2.7
112	L55xTB	9.7	72	207.6	95.5	5.6	2.3	3.5	2.5	2.3	2.5
113	L57xTA	8.0	74	235.5	102.1	77.8	0.0	2.0	3.0	2.8	2.8
114	L57xTB	9.0	74	221.2	102.8	7.9	2.2	2.7	3.0	2.5	2.7
115	L58xTA	10.0	71	214.7	91.7	58.6	2.5	2.8	3.8	2.5	2.0
116	L58xTB	9.6	70	206.8	92.4	0.0	0.0	3.0	3.5	2.0	2.5
117	L59xTA	8.6	69	216.0	99.6	58.4	2.5	1.9	2.3	2.7	2.5
118	L59xTB	7.1	74	190.7	71.8	0.0	8.8	2.7	2.3	2.5	2.8
119	L60xTA	10.6	66	227.2	93.7	9.5	4.8	2.4	2.8	2.5	2.5
120	L60xTB	9.4	68	207.8	78.8	2.4	13.1	3.6	3.3	2.5	2.2
121	L61xTA	8.5	68	237.5	98.4	5.0	8.4	2.3	2.8	2.5	2.5
122	L61xTB	8.1	69	212.2	90.0	0.0	3.0	3.1	2.8	2.5	2.5
123	L62xTA	8.6	69	227.7	91.5	19.1	7.3	2.2	3.3	2.7	2.3
124	L62xTB	8.0	68	216.9	86.2	12.5	5.0	2.7	4.0	2.8	2.8
125	L63xTA	10.8	67	219.2	98.4	78.9	0.0	2.7	3.0	2.0	2.7
126	L63xTB	6.4	71	205.4	82.6	22.9	2.3	2.9	3.0	2.8	3.0
127	L64xTA	10.4	72	207.8	89.1	11.9	9.2	2.5	2.5	2.8	2.8
128	L64xTB	7.6	72	197.7	78.9	0.0	7.5	3.0	2.0	2.5	2.5
129	L65xTA	8.5	68	222.7	93.8	55.7	3.2	2.0	2.5	2.4	1.9
130	L65xTB	2.8	75	161.7	62.2	0.0	11.1	2.7	2.5	3.0	3.3
131	YM020-5xTA	10.3	72	209.4	86.3	0.0	4.8	2.5	2.5	2.5	2.5
132	YM020-9xTA	9.6	72	215.4	91.6	16.7	5.6	1.9	3.0	2.5	2.3
133	WY21	12.1	69	211.2	91.2	22.0	9.6	2.2	3.0	2.5	2.3

Appendix V. Mean performance of testcrosses for grain yield and yield related traits at Shikusa.

Entry	Testcross	GY T/Ha	AD #days	PH cm	EH cm	HC %	ER %	GLS (1-5)	NLB (1-5)	ER (1-5)	PA
1	L1xTA	7.5	71	237.7	105.9	57.8	11.8	2.0	2.5	3.3	2.8
2	L1xTB	6.5	74	233.8	101.2	13.2	9.8	2.3	2.5	3.0	2.3
3	L2xTA	6.0	70	241.9	105.4	17.2	3.8	1.9	2.4	2.5	2.5
4	L2xTB	8.6	72	232.9	81.0	-0.8	2.0	2.0	3.0	2.8	2.5
5	L3xTA	9.4	73	258.5	124.8	12.6	3.5	2.0	2.0	2.5	2.3
6	L3xTB	8.3	73	247.1	119.1	0.4	0.5	2.1	2.7	3.0	2.5
7	L4xTA	7.9	73	253.8	125.0	18.8	3.7	2.0	2.6	2.5	2.3
8	L4xTB	8.8	73	250.2	120.8	0.9	0.0	2.0	2.0	2.3	2.0
9	L5xTA	7.1	72	237.1	102.5	20.6	6.5	3.5	3.2	3.0	2.5
10	L5xTB	8.2	73	226.1	91.8	8.5	11.2	2.6	2.6	2.8	2.7
11	L6xTA	9.2	69	244.8	118.1	25.8	-0.3	2.1	2.7	2.5	2.5
12	L6xTB	6.8	71	249.7	108.5	3.7	5.4	2.2	2.6	2.3	2.5
13	L7xTA	7.9	74	252.5	110.5	2.4	-1.5	2.0	2.5	2.5	2.2
14	L7xTB	6.3	76	231.2	101.9	0.7	2.7	3.5	2.8	3.5	2.7
15	L8xTA	6.9	70	234.9	98.3	54.4	15.2	2.3	2.8	3.3	2.8
16	L8xTB	7.6	75	182.1	74.7	7.9	9.6	3.8	2.2	4.0	3.3
17	L9xTA	6.7	71	248.0	116.8	7.9	17.0	2.3	2.4	3.3	2.7
18	L9xTB	4.2	76	232.0	102.0	16.3	5.6	4.1	2.2	3.3	3.0
19	L10xTA	8.3	70	228.7	96.3	28.7	6.7	2.0	3.1	2.5	2.8
20	L10xTB	4.0	74	206.5	81.4	-2.0	34.8	2.3	3.2	3.8	3.0
21	L11xTA	8.7	74	238.4	98.7	14.8	4.3	2.1	2.7	2.3	2.7
22	L11xTB	7.5	76	214.9	91.0	2.4	9.2	4.4	2.2	3.3	2.7
23	L12xTA	9.3	69	252.2	118.1	70.5	1.8	1.9	2.5	2.8	2.5
24	L12xTB	9.8	73	245.8	115.7	2.7	-0.5	2.3	2.8	2.0	2.0
25	L13xTA	8.3	69	240.6	112.4	24.6	3.6	2.0	2.1	2.8	2.5
26	L13xTB	8.0	72	232.5	98.7	-2.8	2.5	2.5	2.5	2.5	2.5
27	L14xTA	8.0	74	226.5	116.7	2.6	2.1	2.5	2.5	2.3	2.7
28	L14xTB	7.9	74	229.2	112.3	-1.6	12.4	4.9	2.8	2.3	2.8
29	L15xTA	8.2	67	228.0	88.4	3.7	1.9	2.0	2.7	2.0	2.5
30	L15xTB	7.5	70	210.9	81.5	0.9	1.9	2.0	2.9	2.5	2.7
31	L16xTA	10.4	70	229.9	104.5	8.1	0.6	2.1	2.8	2.0	2.3
32	L16xTB	5.0	73	205.9	80.0	1.4	12.2	2.5	2.8	3.5	2.8
33	L17xTA	9.7	71	248.9	118.9	30.2	9.8	2.1	2.7	2.8	2.3
34	L17xTB	8.4	71	247.2	114.4	0.0	2.3	2.9	2.6	2.3	2.3
35	L18xTA	9.9	75	233.3	114.5	40.1	-0.6	2.0	2.5	2.8	2.2
36	L18xTB	7.0	74	201.7	97.7	10.9	1.5	2.0	2.8	3.0	2.8
37	L19xTA	9.9	71	244.4	121.6	45.7	1.6	2.0	2.3	3.3	2.0

38	L19xTB	8.4	73	229.4	98.8	-4.0	0.8	2.4	2.6	3.3	2.5
39	L20xTA	7.8	71	242.6	122.3	5.1	2.3	2.1	2.3	2.5	2.5
40	L20xTB	6.7	74	235.9	99.0	-0.3	-0.7	2.6	2.6	2.8	2.3
41	L21xTA	7.2	71	226.8	106.8	36.3	9.2	1.9	2.3	3.3	2.5
42	L21xTB	8.3	73	210.9	91.8	2.8	7.6	1.9	2.3	2.5	2.3
43	L22xTA	6.8	72	249.1	125.5	0.9	2.5	2.0	2.3	2.8	2.8
44	L22xTB	7.6	73	230.2	103.4	3.0	10.2	4.9	2.3	3.3	3.2
45	L23xTA	9.0	72	246.5	101.3	6.2	2.1	2.1	3.1	1.8	2.2
46	L23xTB	3.1	78	177.0	66.8	0.8	45.3	3.4	2.5	4.0	3.0
47	L24xTA	8.5	71	230.9	99.4	45.3	14.1	1.9	2.1	3.0	2.7
48	L24xTB	4.0	75	198.1	74.5	10.5	15.2	2.5	2.0	3.8	3.0
49	L25xTA	8.6	73	236.1	100.6	13.9	10.1	3.5	2.0	2.5	2.5
50	L25xTB	3.9	76	206.4	84.4	1.6	24.8	3.5	2.3	3.5	2.7
51	L26xTA	9.1	73	257.3	130.3	46.8	6.5	3.4	2.5	2.5	2.3
52	L26xTB	9.8	73	245.0	123.8	-1.5	-0.8	2.0	2.5	2.0	2.0
53	L27xTA	9.0	74	242.9	120.2	30.8	8.9	3.5	2.5	2.3	2.3
54	L27xTB	7.7	74	239.0	112.1	-0.8	4.5	2.1	2.7	2.3	2.0
55	L28xTA	10.1	70	240.3	95.3	39.2	2.1	2.0	2.8	2.8	2.3
56	L28xTB	4.9	74	226.3	83.1	3.9	11.8	3.4	2.8	3.5	2.8
57	L29xTA	7.7	71	246.6	103.8	-5.8	13.5	1.9	2.3	2.3	2.0
58	L29xTB	3.1	76	219.3	84.9	-2.2	43.9	2.5	2.3	3.8	2.5
59	L30xTA	8.6	72	243.4	114.1	4.9	9.6	2.0	2.5	2.8	2.3
60	L30xTB	4.2	74	224.2	98.5	-2.3	8.2	4.3	2.3	3.5	2.5
61	L31xTA	7.9	71	241.9	109.0	22.0	-0.9	2.0	3.3	3.0	2.5
62	L31xTB	9.1	73	257.8	121.9	-1.9	1.5	5.0	2.3	2.8	2.5
63	L32xTA	6.2	73	234.3	91.8	26.8	10.0	2.0	3.0	3.5	3.0
64	L32xTB	6.1	72	234.9	95.9	4.3	-1.3	2.3	2.8	2.8	2.0
65	L33xTA	7.2	68	233.5	86.7	-3.8	9.1	3.5	3.0	2.8	2.3
66	L33xTB	6.2	72	216.8	77.4	8.9	16.0	1.8	2.5	2.8	2.5
67	L34xTA	10.6	73	243.7	120.4	12.9	2.3	2.1	2.2	2.3	2.5
68	L34xTB	8.9	73	230.5	101.3	8.2	11.4	2.2	2.2	2.5	2.5
69	L35xTA	11.9	73	258.1	139.0	22.9	11.2	2.0	2.3	2.0	2.3
70	L35xTB	8.9	75	250.5	125.2	1.3	3.3	2.0	2.5	2.0	2.0
71	L36xTA	8.1	70	234.8	103.2	2.0	5.9	1.9	2.2	2.3	2.3
72	L36xTB	8.1	71	227.4	97.4	-3.5	17.2	2.1	2.3	2.8	2.0
73	L37xTA	9.6	71	228.8	111.7	15.2	8.5	2.0	2.8	2.5	2.3
74	L37xTB	8.1	72	244.8	109.3	-4.0	3.6	3.3	2.6	2.5	2.3
75	L38xTA	9.9	70	249.9	112.1	46.0	-1.1	1.9	2.3	2.8	2.5
76	L38xTB	9.9	72	253.5	122.3	1.1	7.3	2.5	2.3	2.5	2.3
77	L39xTA	7.4	67	221.6	98.8	28.1	4.9	1.9	3.0	2.3	2.5
78	L39xTB	7.9	67	209.4	80.7	0.1	-0.9	3.5	2.5	2.8	2.5
79	L40xTA	9.9	72	239.8	107.8	3.0	0.8	1.9	2.8	2.3	2.5
80	L40xTB	8.4	74	232.6	116.4	-0.4	0.3	2.0	2.7	2.8	2.2

81	L44xTA	8.0	71	258.1	115.7	57.6	17.2	2.6	3.0	3.5	2.5
82	L44xTB	7.5	73	259.7	109.5	2.6	0.2	5.1	2.5	2.3	2.3
83	L42xTA	8.8	71	237.6	112.4	72.2	-4.8	2.4	2.7	3.5	2.5
84	L42xTB	4.6	74	227.9	97.6	2.3	3.5	2.1	2.5	2.3	2.5
85	L43xTA	8.9	71	241.0	114.9	24.7	2.6	2.1	3.0	2.5	2.7
86	L43xTB	7.0	73	231.0	104.4	1.4	8.2	4.0	3.1	2.8	2.5
87	L44xTA	9.7	70	227.1	119.1	12.3	6.6	3.4	2.3	2.5	2.5
88	L44xTB	7.7	73	232.2	125.5	3.0	5.4	2.9	2.8	3.3	2.7
89	L45xTA	11.9	72	256.6	129.7	21.2	4.0	2.0	2.5	2.0	2.3
90	L45xTB	9.0	73	245.4	119.1	16.9	13.4	2.6	2.0	2.0	2.3
91	L46xTA	6.4	72	246.7	111.8	23.1	-1.8	2.1	2.8	2.5	2.5
92	L46xTB	8.9	73	234.0	105.7	4.8	-2.8	3.1	2.3	2.8	2.5
93	L47xTA	11.1	73	253.7	127.5	48.7	3.2	2.1	2.6	2.3	2.2
94	L47xTB	7.7	75	242.5	123.9	0.1	0.7	2.0	2.5	2.5	2.2
95	L48xTA	8.1	71	244.6	112.4	60.8	5.7	2.6	2.5	3.5	2.7
96	L48xTB	7.7	73	261.5	126.2	32.5	5.5	3.5	2.5	3.5	2.3
97	L49xTA	6.3	73	237.9	92.4	13.1	10.1	2.2	2.2	3.3	2.5
98	L49xTB	8.3	71	227.2	91.1	-2.1	6.2	2.6	2.4	2.5	2.7
99	L50xTA	9.5	73	259.4	118.9	4.0	17.6	2.1	2.2	2.5	2.5
100	L50xTB	7.4	74	260.2	112.8	1.2	-0.8	2.6	3.5	2.8	2.5
101	L55xTA	8.6	70	230.8	107.9	19.0	-1.3	2.1	2.5	2.5	2.5
102	L55xTB	9.5	72	237.2	113.8	2.4	2.2	2.0	2.8	1.8	2.3
103	L52xTA	9.9	71	246.1	121.0	32.4	5.3	2.1	3.1	2.3	2.2
104	L52xTB	8.2	74	233.6	99.4	5.4	14.0	2.1	2.6	2.8	2.5
105	L53xTA	8.8	73	259.0	126.4	43.0	2.4	1.8	2.5	2.5	2.5
106	L53xTB	9.1	74	250.3	118.3	21.8	19.1	2.0	2.8	2.8	2.3
107	L54xTA	7.5	72	242.7	119.2	35.3	2.3	2.1	3.3	3.0	2.5
108	L54xTB	9.7	73	247.2	103.7	16.9	13.2	1.9	2.5	3.0	2.3
109	L55xTA	8.7	72	237.0	109.5	83.6	34.7	1.8	2.5	3.8	2.5
110	L55xTB	7.7	73	229.0	101.4	7.5	1.4	3.8	2.8	2.5	2.5
111	L55xTA	9.8	73	229.8	108.4	25.8	9.3	2.0	2.0	2.5	2.3
112	L55xTB	6.7	73	217.2	97.7	6.5	14.9	2.8	2.8	2.8	2.5
113	L57xTA	9.6	73	257.8	123.4	56.6	1.6	2.0	2.5	3.0	2.5
114	L57xTB	8.9	75	236.9	124.2	6.1	0.8	2.9	2.7	2.5	2.5
115	L58xTA	9.1	73	242.8	118.5	35.4	4.5	2.0	2.0	2.8	2.3
116	L58xTB	9.6	74	243.4	106.4	1.8	7.5	2.2	2.6	2.0	2.3
117	L59xTA	7.1	74	242.2	115.2	15.7	1.9	2.3	2.6	2.8	2.5
118	L59xTB	8.0	74	227.4	99.3	2.6	15.7	2.7	2.3	3.0	2.5
119	L60xTA	9.7	72	260.0	114.6	0.4	3.5	2.0	2.5	2.0	2.5
120	L60xTB	8.4	71	241.5	97.6	2.4	4.4	3.2	2.3	2.3	2.3
121	L61xTA	7.5	71	265.0	113.5	13.3	10.7	2.0	2.5	2.8	2.5
122	L61xTB	8.3	72	240.5	102.8	0.6	1.6	2.7	2.6	2.8	2.3
123	L62xTA	5.9	71	255.3	111.9	14.6	14.7	2.0	3.7	3.3	2.8

124	L62xTB	6.3	70	236.7	94.3	-1.5	5.0	3.1	2.9	2.8	2.2
125	L63xTA	8.0	71	236.8	101.5	16.1	0.8	2.5	2.1	3.0	2.3
126	L63xTB	4.8	74	232.3	92.0	19.0	10.0	2.1	2.7	3.3	2.5
127	L64xTA	6.9	74	233.4	107.1	31.8	12.1	2.1	2.0	3.0	2.8
128	L64xTB	7.7	74	231.8	111.2	0.8	18.3	3.6	2.3	3.0	2.3
129	L65xTA	9.7	71	244.2	101.5	35.9	3.7	2.0	2.7	2.8	2.3
130	L65xTB	2.8	81	181.2	67.7	13.9	5.0	3.6	2.0	4.0	3.3
131	YM020-5xTA	8.5	74	249.7	107.9	2.1	11.5	2.1	2.5	2.3	2.0
132	YM020-9xTA	10.7	73	242.9	114.7	5.4	3.0	2.2	2.2	2.3	2.0
133	WY21	8.5	72	237.9	96.8	9.0	1.9	2.5	2.7	2.5	2.5

Appendix XI. Mean performance of testcrosses for grain yield and yield related traits across testing locations.

Entry	Testcross	GY T/Ha	AD #days	PH cm	EH cm	HC %	ER %	GLS (1-5)	NLB (1-5)	ER (1-5)	PA
1	L1xTA	9.9	72	240.3	112.2	67.2	6.7	2.0	2.6	2.9	2.8
2	L1xTB	7.5	75	229.0	99.4	46.7	12.9	3.1	2.4	2.7	2.7
3	L2xTA	8.8	71	237.2	110.9	15.9	4.9	2.0	3.0	2.3	2.4
4	L2xTB	9.4	73	227.2	87.7	4.1	1.8	2.6	3.1	2.6	2.3
5	L3xTA	9.7	74	257.5	129.9	34.1	0.9	2.0	2.7	2.7	2.7
6	L3xTB	9.8	75	245.1	115.5	5.6	1.2	2.9	2.7	2.6	2.5
7	L4xTA	10.8	75	253.8	131.2	62.5	5.6	2.0	2.7	2.6	2.6
8	L4xTB	10.1	77	241.4	117.6	3.1	3.2	2.7	2.3	2.2	2.3
9	L5xTA	9.4	73	240.7	106.4	22.5	14.3	2.5	3.3	2.8	2.4
10	L5xTB	8.6	75	223.0	93.9	18.1	17.9	3.0	3.5	2.8	2.9
11	L6xTA	9.9	71	244.6	118.1	64.6	3.5	2.1	2.9	2.8	2.7
12	L6xTB	8.0	75	248.0	116.8	10.2	10.3	2.9	2.6	2.5	2.5
13	L7xTA	9.7	75	254.6	121.0	31.9	-0.1	2.3	2.6	2.4	2.4
14	L7xTB	8.1	78	237.2	108.2	19.0	4.9	3.9	2.6	2.8	2.7
15	L8xTA	8.7	71	221.9	99.6	65.9	8.7	2.6	2.9	3.0	3.0
16	L8xTB	4.6	77	190.0	75.0	2.0	12.1	4.0	2.3	3.5	3.5
17	L9xTA	8.8	73	247.8	122.2	52.0	9.3	2.2	2.7	2.9	2.8
18	L9xTB	5.5	78	231.2	102.2	25.0	8.3	4.0	2.4	3.2	3.0
19	L10xTA	9.5	71	226.8	100.3	48.2	3.3	2.2	2.7	2.6	2.9
20	L10xTB	4.8	75	205.1	85.3	1.7	25.0	3.3	3.0	3.2	3.0
21	L11xTA	10.5	76	232.8	102.8	29.0	10.8	2.2	2.7	2.4	2.8
22	L11xTB	8.0	78	215.3	95.4	2.5	16.0	3.7	2.4	3.0	2.7
23	L12xTA	10.6	72	251.8	122.8	72.5	2.1	1.8	2.5	2.5	2.6
24	L12xTB	10.8	76	246.3	116.1	11.3	8.9	2.8	2.6	2.3	2.0
25	L13xTA	9.2	71	243.4	116.8	58.9	2.6	2.3	2.6	2.7	2.7
26	L13xTB	8.6	73	229.8	101.8	5.8	1.7	2.8	2.8	2.3	2.5
27	L14xTA	9.0	75	224.1	118.4	13.0	3.0	3.0	2.4	2.3	2.7
28	L14xTB	8.2	75	226.5	115.5	0.1	7.7	4.7	2.7	2.4	2.9
29	L15xTA	9.7	69	227.3	90.9	8.9	2.1	2.1	2.8	2.2	2.3
30	L15xTB	8.4	72	217.5	89.4	0.0	4.4	2.5	3.0	2.4	2.4

31	L16xTA	10.8	71	230.7	107.2	27.5	4.0	2.3	2.8	2.3	2.7
32	L16xTB	6.3	74	211.5	86.4	0.0	20.8	3.0	2.5	3.1	2.7
33	L17xTA	10.6	72	249.7	123.4	61.8	4.7	1.9	2.7	2.8	2.6
34	L17xTB	9.8	75	239.8	119.1	15.9	0.9	2.5	2.3	2.5	2.5
35	L18xTA	9.4	77	234.8	120.2	55.0	1.4	2.1	2.3	2.7	2.8
36	L18xTB	7.7	77	199.2	98.2	14.0	3.6	2.4	2.4	2.9	2.9
37	L19xTA	10.3	73	236.4	123.4	56.6	0.8	2.4	2.5	2.8	2.5
38	L19xTB	9.3	75	233.7	109.2	0.0	3.7	2.6	2.4	2.5	2.3
39	L20xTA	9.7	73	241.9	127.0	33.3	3.3	2.0	2.3	2.3	2.5
40	L20xTB	9.3	75	231.5	107.1	2.6	4.5	2.8	2.5	2.3	2.3
41	L21xTA	9.0	72	227.0	108.4	58.2	5.6	2.0	2.2	2.9	3.0
42	L21xTB	9.3	76	218.9	103.5	3.4	5.5	2.5	2.0	2.5	2.1
43	L22xTA	9.9	73	245.1	129.2	17.0	3.5	2.2	2.3	2.5	2.7
44	L22xTB	7.6	75	230.5	108.6	2.4	9.9	4.5	2.5	2.9	2.8
45	L23xTA	10.4	73	241.2	99.4	28.5	4.5	2.6	2.8	2.2	2.5
46	L23xTB	2.8	80	176.5	69.7	0.0	32.2	4.1	2.6	3.7	3.6
47	L24xTA	8.9	72	235.3	106.8	66.4	8.4	2.0	2.4	2.8	2.8
48	L24xTB	4.4	77	196.7	77.0	2.4	21.8	2.8	2.2	3.4	3.1
49	L25xTA	9.4	75	234.7	111.0	37.4	15.9	2.6	2.1	2.7	2.7
50	L25xTB	4.2	79	207.9	97.2	14.3	21.4	3.5	2.5	3.1	2.9
51	L26xTA	10.4	74	249.8	125.5	61.9	7.1	2.7	2.4	2.6	2.6
52	L26xTB	10.0	75	238.5	126.7	0.0	5.2	2.6	2.2	2.3	2.2
53	L27xTA	10.0	76	237.9	120.8	31.1	4.2	2.6	2.5	2.2	2.5
54	L27xTB	10.0	77	233.2	109.2	0.0	6.2	2.3	2.6	2.1	2.1
55	L28xTA	9.5	71	237.9	103.4	67.8	7.7	2.6	2.4	2.8	2.6
56	L28xTB	5.1	77	218.7	87.5	19.4	12.5	3.6	2.7	3.4	2.8
57	L29xTA	9.0	73	248.0	114.8	5.6	15.4	2.1	2.4	2.3	2.0
58	L29xTB	3.6	79	217.0	89.2	0.0	29.0	3.6	2.5	3.5	3.1
59	L30xTA	9.3	73	249.3	116.3	33.0	7.4	2.4	2.9	2.7	2.4
60	L30xTB	5.9	76	228.9	105.7	7.8	5.7	4.2	2.3	3.0	2.7
61	L31xTA	9.7	73	249.4	115.5	57.6	1.0	2.6	2.7	2.8	2.8
62	L31xTB	9.6	75	254.8	124.2	20.6	-0.1	4.4	2.6	2.6	2.7
63	L32xTA	6.9	74	233.0	103.3	54.3	11.9	2.1	3.0	3.2	3.3
64	L32xTB	7.3	76	240.4	101.3	38.7	3.9	2.4	2.9	2.7	2.6
65	L33xTA	8.8	69	234.9	99.0	15.4	13.8	2.5	2.8	2.5	2.6

66	L33xTB	7.6	72	220.3	82.8	6.5	18.8	2.6	3.1	2.7	2.6
67	L34xTA	10.9	73	248.9	127.7	48.1	4.8	2.2	2.5	2.5	2.7
68	L34xTB	9.6	74	225.6	106.2	6.4	14.0	3.0	2.1	2.3	2.6
69	L35xTA	10.9	76	261.2	140.7	20.4	9.2	2.1	2.2	2.3	2.4
70	L35xTB	11.0	79	250.9	126.9	2.0	5.3	2.2	2.3	2.1	2.0
71	L36xTA	7.8	72	229.0	103.0	19.2	15.5	2.2	2.8	2.4	2.5
72	L36xTB	10.2	73	220.7	96.7	0.0	20.1	2.7	2.4	2.6	2.1
73	L37xTA	10.7	72	235.7	113.1	46.6	3.9	2.1	2.5	2.4	2.3
74	L37xTB	8.7	74	240.9	111.5	0.9	6.8	2.6	2.6	2.3	2.6
75	L38xTA	9.8	71	253.0	116.4	59.0	2.2	2.1	2.5	2.8	2.6
76	L38xTB	9.9	75	250.8	119.1	1.7	13.8	3.2	2.4	2.4	2.4
77	L39xTA	9.8	69	214.6	98.5	42.4	1.6	2.5	2.8	2.5	2.5
78	L39xTB	8.3	70	220.6	93.1	5.7	1.7	4.1	2.6	2.3	2.7
79	L40xTA	10.5	76	245.8	124.4	39.3	1.6	1.9	2.6	2.2	2.8
80	L40xTB	9.5	77	235.9	119.5	4.0	1.9	2.6	2.6	2.5	2.4
81	L44xTA	9.8	73	245.7	118.9	81.4	4.2	2.3	3.0	3.1	2.8
82	L44xTB	8.8	76	260.7	118.7	19.5	3.3	3.9	3.1	2.2	2.6
83	L42xTA	9.1	73	240.5	117.5	81.7	0.5	2.1	2.8	3.0	2.8
84	L42xTB	7.3	76	228.2	103.7	4.7	6.6	2.6	3.0	2.4	2.6
85	L43xTA	10.5	72	242.7	120.5	38.1	2.2	2.5	2.6	2.5	2.8
86	L43xTB	9.3	75	233.6	107.6	4.1	7.7	3.5	2.9	2.4	2.5
87	L44xTA	10.8	72	225.4	126.2	24.2	5.1	2.5	2.5	2.3	2.7
88	L44xTB	10.1	74	243.8	127.7	0.9	7.7	3.5	2.4	2.6	2.7
89	L45xTA	12.4	74	259.4	125.8	48.5	5.1	1.9	2.4	2.3	2.7
90	L45xTB	10.9	75	236.9	113.2	26.7	22.0	2.6	2.3	2.3	2.1
91	L46xTA	7.4	75	243.1	116.2	20.0	-0.2	2.4	2.8	2.6	2.7
92	L46xTB	8.8	77	238.2	113.8	11.5	-0.1	3.2	2.7	2.5	2.4
93	L47xTA	11.2	74	249.0	142.8	70.6	1.5	2.3	2.3	2.7	2.7
94	L47xTB	8.8	78	242.3	124.2	2.2	4.8	2.8	2.6	2.2	2.6
95	L48xTA	9.0	73	249.3	121.1	72.4	3.6	2.8	2.6	3.2	2.9
96	L48xTB	8.2	76	260.4	121.6	12.8	9.0	3.9	2.4	3.1	2.6
97	L49xTA	8.6	73	236.1	96.4	24.7	14.1	2.3	2.8	2.6	2.8
98	L49xTB	10.1	72	225.6	91.2	6.7	7.4	3.2	3.0	2.2	2.4
99	L50xTA	9.5	74	260.8	120.9	2.5	10.1	2.4	2.8	2.4	2.6
100	L50xTB	8.0	77	250.4	108.2	4.0	10.2	3.4	2.7	2.7	2.4
101	L55xTA	9.3	71	229.5	114.2	40.6	2.1	2.1	2.7	2.6	2.5

102	L55xTB	9.4	74	232.3	117.6	2.4	4.3	2.1	2.8	2.2	2.3
103	L52xTA	10.4	72	241.1	123.3	47.1	3.2	2.4	2.7	2.2	2.3
104	L52xTB	9.5	74	232.0	105.2	0.1	12.5	3.1	2.2	2.7	2.5
105	L53xTA	9.5	75	257.1	136.8	75.1	1.3	1.9	2.4	2.6	2.7
106	L53xTB	10.3	77	254.2	123.5	35.8	14.0	2.6	2.8	2.8	2.5
107	L54xTA	8.4	74	244.2	121.0	44.9	1.2	2.0	2.7	2.9	2.7
108	L54xTB	10.3	75	242.0	108.9	40.0	10.1	2.7	2.9	2.8	2.1
109	L55xTA	9.2	74	237.2	114.9	89.5	13.5	2.6	2.4	3.2	2.9
110	L55xTB	8.9	77	223.3	101.9	32.3	2.4	3.8	2.7	2.4	2.8
111	L55xTA	10.0	73	230.1	107.7	43.0	9.8	2.2	2.3	2.8	2.7
112	L55xTB	8.4	76	217.7	100.8	9.0	13.5	3.4	2.7	2.6	2.5
113	L57xTA	9.4	76	255.3	126.8	78.4	0.6	2.3	2.7	2.6	2.7
114	L57xTB	9.7	77	241.9	127.1	10.1	1.6	3.2	2.7	2.3	2.8
115	L58xTA	9.9	75	243.5	120.6	39.7	2.7	2.6	2.9	2.7	2.4
116	L58xTB	9.3	74	235.1	111.6	2.5	5.2	2.9	2.9	2.2	2.6
117	L59xTA	8.2	74	241.5	119.5	51.4	2.1	2.3	2.1	2.8	2.5
118	L59xTB	8.0	77	227.2	98.8	0.8	18.5	2.8	2.2	2.8	2.8
119	L60xTA	10.8	71	261.1	115.5	9.7	11.2	2.3	2.4	2.3	2.3
120	L60xTB	9.6	72	241.7	101.4	10.3	6.9	3.6	2.5	2.4	2.5
121	L61xTA	9.3	72	267.5	118.0	16.6	10.4	2.3	2.6	2.4	2.7
122	L61xTB	8.6	73	240.1	109.7	10.6	2.6	3.3	2.4	2.5	2.6
123	L62xTA	7.7	73	254.2	113.9	18.8	11.9	2.3	3.3	2.9	2.9
124	L62xTB	8.3	73	240.4	102.3	10.0	3.9	3.1	3.0	2.6	2.7
125	L63xTA	10.0	71	239.9	113.6	47.9	0.1	2.6	2.5	2.4	2.6
126	L63xTB	6.0	76	230.8	99.6	19.0	4.6	2.8	2.6	2.8	3.2
127	L64xTA	8.8	74	234.9	110.5	40.0	13.7	2.4	2.5	3.1	2.7
128	L64xTB	8.8	76	227.3	108.0	8.8	11.1	3.2	2.1	2.7	2.4
129	L65xTA	9.7	72	244.7	108.1	54.4	4.9	2.2	2.4	2.7	2.4
130	L65xTB	3.1	80	183.8	76.5	18.9	14.0	3.2	2.3	3.5	3.3

Appendix VII. GCA for grain yield and yield related traits at Chorlim.

					GCA					
Lines	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	0.4	0.0	-6.3	-7.8	36.1*	4.5	0.1	-0.4	0.3	0.2
2	0.5	-1.9	-4.6	-14.4	-27.0	-8.3**	-0.5	0.7*	-0.4	-0.6
3	0.4	1.1*	15.8	12.8	-11.2	-12.2**	0.1	0.1	0.1	-0.1
4	1.6	1.0	11.2	14.5	5.2	-1.9**	-0.2	0.0	-0.1	-0.1
5	0.0	-1.1	-0.5	-12.8	4.9	17.1	-0.7	1.2***	0.1	-0.3
6	0.0	-1.5	9.3	6.7	16.2	2.4	-0.2	-0.1	0.3	0.2
7	-0.3	1.7	7.2	0.6	20.8	-4.0**	0.6	-0.3	-0.3	0.2
8	-3.2*	-0.3	-48.1***	-33.4*	-3.8	2.1	0.8	-0.1	0.6	0.9**
9	-1.2	2.25*	9.0	3.9	5.2	-1.7**	0.3	-0.3	0.4	0.2
10	-1.1	-1.9	-17.1	-17.9	8.2	0.1	0.6	0.3	0.0	-0.1
11	0.4	2.4	-18.4	-18.5	-11.7	7.0	-0.2	-0.3	0.0	0.2
12	1.4	-0.3	11.5	12.0	16.7	1.2	-0.2	0.0	-0.1	-0.3
13	-1.2	-3.8	0.4	-3.3	9.4	-9.0**	-0.5	0.74*	-0.1	-0.1
14	-0.3	0.9	-4.3	8.3	-21.9	-6.6**	1.3*	-0.2	-0.4	0.2
15	-0.4	-3.7	-12.2	-23.8	-26.8	-5.0**	-0.7	0.5	-0.5	-0.8*
16	-0.6	-2.1*	-9.6	-15.7	-7.8	7.9	0.1	-0.1	0.0	-0.1
17	1.1	-0.5	11.7	13.5	23.1	-8.6**	-1.0	0.1	0.4	-0.1
18	-0.8	3.4	-21.5	-2.1	10.9	-5.2**	-0.7	-0.4	0.1	0.2
19	0.8	0.8	-1.1	7.8	-0.7	-7.38**	0.1	-0.2	-0.3	-0.3
20	1.4	0.0	-4.2	4.6	-1.9	-4.58**	-0.5	-0.4	-0.6	-0.5
21	-0.1	-0.4	-10.4	-2.8	16.0	-4.23**	-0.5	-0.4	0.3	-0.1
22	-0.5	0.5	2.5	10.6	-18.6	1.4	0.3	0.1	0.0	-0.1
23	-3.2*	2.9	-30.6*	-32.7*	-13.3	6.1	1.1	0.0	0.5	0.7*
24	-3.3*	-0.3*	-22.9	-26.0	1.7	15.1	-0.5	-0.4	0.6*	0.4
25	-2.6	3.7	-20.7	3.1	-4.0	18.4	0.1	-0.1	0.4	0.2
26	0.1	1.4	8.1	16.1	3.8	-0.3**	-0.2	-0.3	0.0	-0.1
27	1.3	2.1	0.4	9.3	-16.4	-4.7**	-0.5	-0.2	-0.6	-0.6
28	-1.8	0.0	-8.2	-12.7	8.1	4.6	0.3	0.1	0.64*	-0.1
29	-2.8*	2.0	-8.3	-9.9	-28.8	17.7	0.8	-0.2	0.3	0.2
30	-1.4	0.4	10.4	1.4	1.1	-4.4**	0.8	-0.1	0.1	-0.1
31	0.9	-0.4	18.2	10.6	32.9	-9.1**	0.8	0.1	0.0	0.2
32	-0.7	0.4	0.2	-6.1	30.0	4.3	-1.0	0.5	0.4	0.5
33	-0.6	-3.7	-7.4	-20.9	-20.4	12.0	-0.5	0.5	-0.2	-0.1
34	1.0	0.3	4.5	8.9	-0.5	5.6	-0.2	0.0	-0.1	-0.1
35	3.5*	3.3	20.4	25.2	-21.9	0.9	-0.7	-0.3	-0.3	-0.6
36	-0.1	-2.4	-15.9	-14.8	-34.7*	21.5	-0.2	-0.3	0.0	-0.1
37	0.2	-1.2	-2.1	-3.3	-12.2	-3.6**	-1.0	0.2	-0.3	-0.1
38	2.5	-1.7	21.5	12.6	8.8	4.5	0.1	-0.2	0.0	-0.1

39	0.1	-3.6	-19.1	-18.0	4.9	-8.3**	1.1	0.1	-0.4	-0.1
40	2.3	2.1	7.0	22.0	-5.4	-9.5**	-0.7	0.1	-0.3	-0.1
41	0.9	0.3	4.3	8.6	17.3	-8.1**	0.1	0.77*	-0.2	0.2
42	-0.5	1.9	6.0	5.4	2.9	-1.3**	-0.5	0.5	0.1	-0.1
43	1.9	-0.7	4.8	3.3	-0.9	-3.0**	0.3	-0.1	-0.2	0.2
44	1.6	-1.9	1.1	17.4	-17.4	-2.0**	0.1	-0.2	-0.6*	0.2
45	2.6	2.5	5.6	7.1	22.1	10.3	-0.7	-0.4	0.0	-0.3
46	-1.2	2.0	7.7	10.4	-28.5	-11.0**	0.1	0.4	-0.1	-0.3
47	0.3	1.0	5.0	14.1	-4.2	-4.7**	0.1	-0.1	0.0	0.2
48	-0.2	0.5	22.8	8.6	7.9	-0.9**	0.8	-0.1	0.4	0.2
49	0.8	-1.7	-6.0	-20.4	-10.4	1.5	0.3	0.2	-0.6	-0.3
50	-0.4	0.0	22.3	2.8	-35.7*	7.9	0.6	0.0	0.0	-0.1
51	-0.4	-2.4	-0.7	7.0	-9.8	-5.6**	-1.0	0.2	0.0	-0.3
52	0.9	-1.6	-3.6	5.8	-4.5	2.2	0.6	-0.2	-0.2	-0.3
53	1.9	2.2	25.6	26.2	20.9	-5.2**	-0.5	-0.2	0.1	-0.1
54	0.0	-1.5	6.3	2.2	33.0	-5.7**	-0.2	0.4	0.3	-0.3
55	-0.5	1.7	-3.1	-2.6	20.5	-8.2**	0.8	-0.2	0.1	0.2
56	0.5	-0.3	-21.7	-19.0	16.8	10.2	0.1	0.0	0.4	-0.1
57	0.8	2.6	12.2	21.6	18.0	-9.0**	0.6	0.0	-0.6	0.2
58	-0.4	0.2	2.9	12.0	-21.2	-4.4**	0.3	0.3	0.0	0.2
59	-0.8	1.1	0.7	-1.0	4.9	4.7	-0.2	-0.6	0.4	-0.1
60	1.6	-3.4	23.2	-1.4	-12.6	3.8	0.3	-0.4	-0.1	-0.3
61	0.8	-3.5	19.9	3.9	-5.6	-3.2**	0.3	-0.2	-0.5	0.2
62	-0.5	-1.0	16.5	-0.5	-15.2	-2.4**	0.1	0.0	-0.1	0.4
63	-0.9	0.3	-1.3	-0.9	-6.8	-10.1**	0.1	-0.2	-0.3	0.69*
64	-0.1	-0.8	-0.8	3.7	10.2	3.9	-0.2	0.0	0.4	-0.3
65	-2.5	0.74*	-24.0	-20.0	22.2	5.6	0.1	-0.2	0.5	0.4

Appendix VIII. Specific combining ability estimates with tester A for grain yield and yield related traits at Chorlim.

	SCA TESTER A									
LINE	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	-0.3	0.1	4.0	3.1	-6.3	-10.5**	-0.4	0.0	0.1	-0.1
2	-1.1	0.8	-4.0	7.3	-22.3	5.4	0.1	-0.1	-0.3	0.2
3	-1.8	1.3	4.9	9.1	-6.6	3.9	-0.4	0.4	0.2	0.2
4	-0.3	-0.2	4.8	5.0	20.0	5.5	-0.2	0.0	0.2	0.2
5	0.0	0.2	4.9	0.8	-30.1	-1.4**	-0.2	-0.4	-0.1	-0.1
6	0.3	-1.4	-4.2	-6.5	15.5	-5.3**	-0.2	0.3	0.1	-0.1
7	0.2	-0.5	0.5	1.5	-23.4	-0.9**	-0.4	0.0	-0.1	-0.1
8	2.4	-3.5*	9.3	11.5	11.2	-0.1**	-0.2	0.4	-0.3	-0.3
9	1.2	-0.5	-2.3	3.7	16.1	-0.7**	-0.7	0.4	-0.3	-0.1
10	1.5	-0.8	3.2	3.2	15.7	-6.2**	-0.4	-0.3	0.1	0.2
11	1.3	0.6	0.7	-2.2	-1.5	-2.1**	0.3	0.0	-0.4	-0.1
12	-0.2	-1.3	-0.3	-1.0	14.7	-7.5**	-0.2	0.0	0.0	0.4
13	-0.5	0.2	1.4	-0.4	14.2	4.2	0.6	-0.3	0.2	0.2
14	-0.3	0.6	-11.2	-9.0	-10.9	5.2	-0.2	-0.2	0.0	-0.1
15	0.6	-0.3	-4.7	-7.0	-12.9	0.5	0.3	0.1	-0.2	-0.1
16	1.1	0.0	6.3	8.9	2.8	-4.6**	0.1	0.3	-0.2	0.2
17	-0.8	-1.3	-4.8	-6.9	-2.4	6.2	0.6	0.6	0.2	0.2
18	0.0	1.5	13.6	7.2	9.2	0.7	0.3	0.0	0.0	-0.1
19	-0.4	0.2	2.0	0.1	12.3	2.3	0.6	-0.2	0.3	0.4
20	-1.2	-0.1	3.1	6.8	10.4	0.8	0.1	0.1	0.2	-0.3
21	-0.5	-0.6	-9.1	-9.1	23.6	2.0	0.1	-0.1	0.1	0.7
22	1.3	0.8	-4.1	4.9	-12.5	-2.7**	-0.7	-0.1	-0.2	0.2
23	4.0*	-2.9	27.7*	10.7	-0.1	-10.9**	-0.4	-0.5	-0.9*	-0.6
24	1.1	-1.3	17.4	14.1	14.1	-12.9**	0.1	0.0	-0.3	-0.3
25	1.8	0.6	9.0	-7.3	10.1	1.3	-0.4	-0.3	-0.1	-0.1
26	-0.1	1.1	-9.3	-9.8	14.2	2.3	0.3	0.3	0.1	0.2
27	-0.2	0.5	-4.1	-1.4	-3.3	1.0	0.6	-0.2	0.2	0.2
28	0.7	-1.4	-2.3	-0.9	20.3	-4.9**	-0.2	-0.5	-0.5	0.2
29	2.1	-2.4	11.7	6.6	-17.4	-2.5**	-0.7	-0.2	-0.9*	-1.1**
30	0.6	-0.5	8.1	0.0	6.3	5.0	-0.2	0.2	-0.3	-0.3

31	-0.6	0.1	-8.0	-9.5	-4.4	5.2	-0.2	-0.4	0.1	-0.1
32	0.3	-1.3	-14.2	-5.0	-11.7	7.5	0.6	-0.1	0.2	0.2
33	-1.4	1.0	2.3	1.7	-8.7	2.3	0.1	-0.3	-0.3	0.2
34	0.1	1.2	4.8	8.0	5.1	-4.6**	-0.2	0.5	0.2	0.2
35	-1.1	-0.2	5.5	4.1	-9.7	5.9	0.8	0.1	0.1	0.2
36	-2.3	-0.4	-1.9	-2.9	-22.4	4.4	0.3	0.3	0.1	0.2
37	0.4	0.4	-6.1	-10.1	-1.3	1.4	0.6	-0.6	0.2	-0.3
38	0.0	-0.6	-3.4	-5.1	17.9	-7.5**	-0.4	0.3	0.3	0.2
39	0.6	-1.2	-17.2	-9.0	-0.3	0.5	-0.4	0.0	0.5	0.2
40	0.8	1.0	-0.7	-3.0	7.9	3.0	-0.2	-0.5	-0.2	0.2
41	-0.5	-0.7	-25.1*	-8.7	19.8	-0.9**	0.1	0.0	0.7	-0.1
42	-0.7	0.2	-3.7	-2.5	8.3	-4.8**	0.1	-0.6	0.2	0.2
43	-0.4	-0.4	-1.5	0.4	0.7	-0.7**	0.3	-0.2	0.1	0.4
44	-1.0	1.4	-7.8	-2.0	-5.2	0.3	-0.4	0.2	0.0	-0.1
45	-0.4	1.4	4.5	6.4	3.0	-16.32**	-0.2	-0.1	-0.2	0.4
46	-0.9	0.6	-5.8	-7.0	-14.3	5.0	0.1	0.3	0.2	-0.1
47	-0.8	-0.2	-3.2	-2.5	8.5	-3.0**	0.1	-0.2	0.6	-0.1
48	0.4	0.5	-12.2	-5.0	13.4	-4.5**	-0.2	0.3	0.0	-0.1
49	-1.0	2.8	1.7	-1.5	-10.4	6.7	-0.2	-0.1	0.2	0.4
50	-0.1	-0.6	2.7	7.9	-23.5	-2.5**	0.1	0.5	-0.2	0.2
51	-0.2	-0.1	-4.5	-5.1	-3.6	-2.9**	0.6	0.3	0.1	-0.1
52	0.5	0.6	-4.4	0.2	6.9	-6.6**	0.1	0.3	-0.4	-0.1
53	-1.0	-0.5	-3.3	-2.9	12.8	0.2	0.1	-0.3	0.0	0.2
54	-2.0	0.0	-6.2	-1.2	-13.2	-0.7**	-0.2	-0.3	0.1	0.4
55	-0.5	1.2	-4.1	2.4	1.6	3.3	0.3	-0.3	0.2	-0.1
56	0.3	0.6	3.3	-1.4	8.1	2.1	-0.4	-0.5	0.2	0.2
57	-1.0	0.9	-2.4	-5.0	19.9	3.6	0.1	0.0	0.0	-0.1
58	0.0	2.3	3.1	2.7	-15.2	-0.0**	0.3	0.3	0.1	-0.1
59	-0.7	-0.2	-4.1	1.3	14.6	-10.6**	0.3	-0.3	0.0	-0.3
60	-0.4	1.4	2.3	-2.0	-28.0	14.0	-0.2	0.1	0.0	-0.6
61	0.5	1.5	12.0	0.8	-21.2	9.6	-0.2	0.3	-0.1	-0.1
62	-1.9	1.6	1.0	0.8	-21.0	10.3	0.1	0.6	0.3	0.2
63	1.4	-1.2	-0.7	4.6	-7.3	1.9	0.1	0.2	-0.2	-0.6
64	-2.0	-0.5	-1.3	-4.6	3.0	10.5	0.3	0.5	0.5	-0.1
65	2.7	-1.8	25.0*	9.4	-9.8	-6.0**	0.1	-0.2	-0.4	-0.3

Appendix IX. Specific combining ability estimates with tester B for grain yield and yield related traits at Chorlim.

					SCA_TESTER B					
LINE	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	0.3	-0.1	-4.1	-3.1	6.3	10.4	0.4	0.0	-0.1	0.1
2	1.1	-0.8	4.0	-7.4	22.4	-5.4**	-0.1	0.1	0.3	-0.2
3	1.8	-1.3	-4.9	-9.1	6.7	-3.9**	0.4	-0.4	-0.2	-0.2
4	0.3	0.2	-4.8	-5.1	-19.9	-5.5**	0.2	0.0	-0.2	-0.2
5	0.0	-0.2	-5.0	-0.8	30.1	1.3	0.2	0.4	0.1	0.1
6	-0.3	1.5	4.1	6.4	-15.5	5.2	0.2	-0.3	-0.1	0.1
7	-0.2	0.5	-0.5	-1.6	23.4	0.9	0.4	0.0	0.1	0.1
8	-2.4	3.46*	-9.3	-11.5	-11.2	0.1	0.2	-0.4	0.3	0.3
9	-1.2	0.5	2.2	-3.8	-16.1	0.7	0.7	-0.4	0.3	0.1
10	-1.5	0.8	-3.3	-3.3	-15.7	6.2	0.4	0.3	-0.1	-0.2
11	-1.3	-0.6	-0.8	2.1	1.6	2.1	-0.3	0.0	0.4	0.1
12	0.2	1.3	0.3	0.9	-14.7	7.5	0.2	0.0	0.0	-0.4
13	0.5	-0.2	-1.5	0.3	-14.2	-4.2**	-0.6	0.3	-0.2	-0.2
14	0.3	-0.6	11.1	8.9	10.9	-5.2**	0.2	0.2	0.0	0.1
15	-0.6	0.3	4.7	6.9	12.9	-0.5**	-0.3	-0.1	0.2	0.1
16	-1.1	0.0	-6.3	-8.9	-2.8	4.6	-0.1	-0.3	0.2	-0.2
17	0.8	1.4	4.8	6.8	2.4	-6.3**	-0.6	-0.6	-0.2	-0.2
18	0.0	-1.5	-13.6	-7.2	-9.2	-0.7**	-0.3	0.0	0.0	0.1
19	0.4	-0.2	-2.0	-0.2	-12.3	-2.3**	-0.6	0.2	-0.3	-0.4
20	1.2	0.1	-3.1	-6.9	-10.4	-0.8**	-0.1	-0.1	-0.2	0.3
21	0.5	0.6	9.1	9.0	-23.5	-2.0**	-0.1	0.1	-0.1	-0.7
22	-1.3	-0.8	4.0	-5.0	12.6	2.6	0.7	0.1	0.2	-0.2
23	-4.0*	2.9	-27.7*	-10.8	0.1	10.9	0.4	0.5	0.9*	0.6
24	-1.0	1.3	-17.5	-14.1	-14.0	12.9	-0.1	0.0	0.3	0.3
25	-1.8	-0.6	-9.1	7.2	-10.1	-1.4**	0.4	0.3	0.1	0.1
26	0.1	-1.1	9.3	9.8	-14.2	-2.4**	-0.3	-0.3	-0.1	-0.2
27	0.2	-0.5	4.0	1.4	3.3	-1.1**	-0.6	0.2	-0.2	-0.2
28	-0.7	1.4	2.3	0.8	-20.3	4.9	0.2	0.5	0.5	-0.2
29	-2.1	2.4	-11.7	-6.7	17.5	2.5	0.7	0.2	0.93*	1.1**
30	-0.6	0.6	-8.2	0.0	-6.3	-5.1**	0.2	-0.2	0.3	0.3
31	0.6	-0.1	8.0	9.4	4.5	-5.2**	0.2	0.4	-0.1	0.1
32	-0.3	1.3	14.1	4.9	11.7	-7.5**	-0.6	0.1	-0.2	-0.2
33	1.4	-1.0	-2.4	-1.8	8.7	-2.3**	-0.1	0.3	0.3	-0.2
34	-0.1	-1.2	-4.8	-8.1	-5.1	4.5	0.2	-0.5	-0.2	-0.2
35	1.1	0.2	-5.5	-4.2	9.7	-5.9**	-0.8	-0.1	-0.1	-0.2
36	2.3	0.4	1.9	2.8	22.4	-4.4**	-0.3	-0.3	-0.1	-0.2
37	-0.4	-0.4	6.0	10.0	1.3	-1.4**	-0.6	0.6	-0.2	0.3
38	0.0	0.6	3.3	5.0	-17.8	7.4	0.4	-0.3	-0.3	-0.2

39	-0.6	1.2	17.1	9.0	0.4	-0.6**	0.4	0.0	-0.5	-0.2
40	-0.8	-1.0	0.7	2.9	-7.8	-3.1**	0.2	0.5	0.2	-0.2
41	0.5	0.7	25.0*	8.6	-19.8	0.9	-0.1	0.0	-0.7	0.1
42	0.7	-0.2	3.7	2.4	-8.2	4.7	-0.1	0.6	-0.2	-0.2
43	0.4	0.4	1.5	-0.4	-0.7	0.7	-0.3	0.2	-0.1	-0.4
44	1.0	-1.4	7.7	1.9	5.2	-0.3**	0.4	-0.2	0.0	0.1
45	0.4	-1.4	-4.6	-6.4	-2.9	16.3	0.2	0.1	0.2	-0.4
46	0.9	-0.6	5.8	7.0	14.4	-5.03**	-0.1	-0.3	-0.2	0.1
47	0.8	0.2	3.1	2.4	-8.5	3.0	-0.1	0.2	-0.6	0.1
48	-0.4	-0.5	12.2	4.9	-13.3	4.5	0.2	-0.3	0.0	0.1
49	1.0	-2.8	-1.7	1.5	10.4	-6.7**	0.2	0.1	-0.2	-0.4
50	0.1	0.6	-2.8	-7.9	23.5	2.5	-0.1	-0.5	0.2	-0.2
51	0.2	0.1	4.4	5.0	3.7	2.9	-0.6	-0.3	-0.1	0.1
52	-0.5	-0.6	4.3	-0.2	-6.8	6.6	-0.1	-0.3	0.4	0.1
53	1.0	0.5	3.2	2.9	-12.7	-0.2**	-0.1	0.3	0.0	-0.2
54	2.0	0.0	6.2	1.1	13.3	0.7	0.2	0.3	-0.1	-0.4
55	0.5	-1.2	4.0	-2.5	-1.6	-3.4**	-0.3	0.3	-0.2	0.1
56	-0.3	-0.6	-3.4	1.4	-8.1	-2.6**	0.4	0.5	-0.2	-0.2
57	1.0	-0.9	2.4	5.0	-19.8	-3.6**	-0.1	0.0	0.0	0.1
58	0.0	-2.3	-3.1	-2.7	15.2	0.01**	-0.3	-0.3	-0.1	0.1
59	0.7	0.2	4.1	-1.4	-14.6	10.5	-0.3	0.3	0.0	0.3
60	0.4	-1.4	-2.3	1.9	28.0	-14.1**	0.2	-0.1	0.0	0.6
61	-0.5	-1.5	-12.0	-0.9	21.2	-9.6**	0.2	-0.3	0.1	0.1
62	1.9	-1.6	-1.0	-0.9	21.1	-10.3**	-0.1	-0.6	-0.3	-0.2
63	-1.4	1.2	0.7	-4.7	7.3	-1.9**	-0.1	-0.2	0.2	0.6
64	2.0	0.5	1.2	4.6	-2.9	-10.6**	-0.3	-0.5	-0.5	0.1
65	-2.7	1.8	-25.0*	-9.5	9.8	6.0	-0.1	0.2	0.4	0.3

Appendix X. GCA for grain yield and yield related traits at Mabanga

	GCA									
Lines	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	0.04	-1.88	3.45	-2.45	34.38	-1.07**	-0.18	0.06	-0.15	0.04
2	0.60	-3.40	-6.63	-6.04	-17.02	0.28	-0.10	0.56	-0.14	-06
3	1.17	-1.29*	13.41	7.57	-1.62	-3.32**	-0.36	0.43	-0.12	0.08
4	2.58	2.67	11.63	11.93	20.10	-2.52**	-0.41	-0.07	-0.16	-0.22
5	0.25	0.42	-10.01	-10.36	-23.45	6.63	0.22	0.93*	0.21	0.14
6	-0.34	-1.00	8.10	5.34	16.98	-0.72**	0.01	0.56	0.10	-0.20
7	1.29	2.58	17.48	11.31	-9.72	-4.65**	0.46	0.31	-0.13	-0.36
8	-2.73*	-0.37	-12.69	-15.85	8.53	2.93	0.47	-0.07	0.38*	0.43
9	-1.52	0.84	1.38	0.25	31.95	1.08	0.27	0.31	0.36	0.32
10	-2.53	-0.34	-23.63*	-16.83	-15.47	6.43	-0.01	-0.19	0.33	0.61**
11	0.48	2.90	-7.73	-4.89	-14.00	11.25	0.21	0.31	0.25	-0.06
12	2.42	0.29	14.39	4.30	7.45	-2.5**	-0.66	-0.32	-0.26	-0.35
13	0.87	-1.64	3.46	1.51	8.00	-3.4**	0.23	-0.07	-0.14	-0.10
14	-0.88	-0.24	-16.96	3.70	-23.60	-0.25**	0.92**	-0.19	0.08	0.04
15	0.67	-4.09	-12.13	-16.36	-25.85	-2.4**	-0.01	0.06	-0.01	-0.19
16	-0.04	-1.31	-17.99	-11.49	-18.35	7.48	-0.12	0.06	0.23	0.28
17	1.54	-0.51	1.60	8.03	10.93	-4.65**	-0.54	-0.44	0.00	0.06
18	-0.78	4.04	-17.34	-1.95	1.60	-4.65**	-0.28	-0.32	0.23	0.40
19	0.76	-2.00	0.83	6.12	-1.77	-2.27**	-0.38	-0.19	-0.13	-0.05
20	1.00	-0.93	3.34	10.79	-13.77	-0.8**	-0.25	-0.19	-0.26	-0.07
21	0.79	0.61	-10.20	-1.07	-6.32	-2.27**	-0.42	-0.69	-0.18	0.00
22	0.82	-1.87	-0.96	6.56	-17.40	-2.4**	0.66	-0.32	-0.02	0.07
23	-1.78	1.83	-26.28*	-21.79*	-13.07	8.60	0.68*	-0.07	0.26	0.46*
24	-1.86	0.85*	-16.41	-11.09	9.75	-0.22**	-0.04	-0.07	0.14	0.10
25	-2.32	2.50	-8.76	-10.33	8.63	4.93	-0.01	-0.32	0.12	0.17
26	2.36	-1.6*	7.33	15.00	0.83	1.25	-0.12	-0.57	-0.15	-0.33
27	1.20	3.05	-9.78	-8.08	-19.05	-2.37**	-0.7*	0.06	-0.26	-0.07
28	-2.79*	0.92	-13.49	-15.94	36.20	1.43	0.44	-0.32	0.45*	0.17
29	-2.27	0.86	2.90	-4.12	-27.15	4.53	-0.04	-0.07	0.24	-0.19
30	-0.97	0.86	1.43	-0.16	-10.00	-1.07**	0.34	0.18	0.11	-0.20

31	0.57	-0.5*	17.32	9.06	8.73	-4.65**	0.60	-0.19	-0.04	0.01
32	-2.97*	1.46	2.08	-5.91	28.83	-2.57**	-0.05	0.18	0.09	0.42
33	-0.29	-4.87	-9.76	-15.02	-14.35	9.43	-0.09	0.43	0.11	0.15
34	1.10	-1.48	2.68	8.42	5.58	0.23	0.09	-0.57	-0.10	0.19
35	-0.11	4.37	21.85	20.03*	-19.97	-2.32**	-0.44	-0.44	-0.27	-0.35
36	0.06	-1.06	-13.42	-11.02	-2.10	3.63	-0.05	0.43	-0.15	-0.44
37	1.19	-1.39	6.29	2.38	13.80	-1.07**	-0.26	-0.32	-0.14	-0.36
38	-1.49	-0.59	9.15	-1.88	-7.17	-0.97**	0.03	0.06	-0.06	-0.32
39	0.64	-4.82	-17.11	-13.31	-10.50	-3.52**	0.54	-0.07	0.00	-0.06
40	-0.02	3.91	4.95	4.63	4.55	-2.32**	-0.11	-0.32	-0.34	0.09
41	0.30	0.51	25.9*	12.48	36.55	-3.45**	-0.30	0.56	0.12	0.15
42	-0.57	-0.93	-5.55	-2.40	23.30	-3.4**	-0.41	0.31	-0.02	0.28
43	1.06	-1.28	1.59	4.66	-14.62	-1.85**	0.08	0.18	-0.14	-0.25
44	1.99	-1.44	0.55	15.56	-18.17	2.20	0.28	-0.19	-0.03	-0.08
45	2.73*	-0.44	14.14	-0.09	7.45	6.10	-0.50	-0.07	-0.4*	-0.19
46	-0.91	2.11	1.17	1.32	-5.02	-4.65**	0.07	0.18	-0.01	0.06
47	1.30	1.34	12.16	36.86***	24.90	-3.45**	0.01	-0.32	-0.16	0.03
48	-0.94	1.74	15.13	10.31	8.10	-2**	0.59	-0.19	0.31	0.14
49	1.02	-2.34	-5.72	-14.30	-13.52	5.95	0.08	0.93*	-0.28	0.15
50	-0.61	2.01	18.49	1.05	-22.40	-1.77**	0.26	-0.07	-0.15	-0.34
51	0.33	-0.27	-7.11	5.96	-0.07	-1.07**	-0.42	0.06	-0.13	-0.18
52	0.70	-1.82	0.77	-0.80	-8.35	-4.65**	0.10	-0.44	-0.04	-0.22
53	0.01	1.66	17.61	16.13	46.00*	3.05	-0.34	0.06	0.13	0.15
54	0.61	2.01	4.04	4.02	4.48	0.05	-0.28	-0.19	0.08	-0.11
55	0.42	0.75	-10.48	-2.33	47.2*	-2**	0.40	0.06	0.02	0.31
56	0.21	-0.04	-2.32	2.78	-16.05	-3.52**	0.32	-0.07	-0.12	0.05
57	-0.40	3.41	17.20	10.61	14.48	-3.57**	-0.32	0.18	0.12	0.17
58	0.88	-0.23	-0.37	0.29	0.93	-3.4**	0.26	0.81*	-0.28	-0.36
59	-1.15	1.29	-8.29	-6.28	0.83	1.00	-0.38	-0.57	0.10	0.06
60	1.15	-3.34	6.62	-5.45	-22.40	4.28	0.33	0.18	-0.01	-0.21
61	-0.67	-1.99	13.47	2.34	-25.85	1.00	0.03	-0.07	-0.01	-0.05
62	-0.64	-1.62	11.93	-2.63	-12.57	1.48	-0.18	0.81*	0.23	-0.07
63	-0.36	-1.35	0.91	-1.37	22.55	-3.52**	0.11	0.18	-0.11	0.27
64	0.04	1.50	-8.54	-7.85	-22.40	3.68	0.07	-0.57	0.12	0.07
65	-3.31*	1.22*	-18.85	-13.82	-0.50	2.48	-0.31	-0.32	0.22	0.03

Appendix XI. Specific combining ability estimates with tester A for grain yield and yield related traits at Mabanga.

	SCA-Tester A									
LINE	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	1.8	-0.8	0.0	3.2	-23.8	4.3	-0.1	0.3	0.1	-0.1
2	0.0	0.5	3.5	3.1	-9.7	3.5	0.1	0.1	-0.1	-0.1
3	-0.5	0.0	-1.1	-1.9	1.1	-0.6**	0.1	0.0	0.1	0.1
4	0.4	0.2	0.1	1.0	23.0	0.7	0.2	0.2	0.1	0.1
5	0.1	-0.3	2.3	2.2	-11.2	3.3	-0.3	0.0	0.0	-0.5
6	0.0	-0.8	-10.5	-6.5	14.3	1.7	0.0	0.1	0.2	0.4
7	-0.1	-0.6	0.3	0.3	2.6	0.8	-0.2	0.1	-0.1	-0.2
8	2.7	-0.9	0.0	1.0	20.8	-2.1**	-0.3	0.2	-0.1	-0.2
9	1.0	-1.8	3.4	5.6	-10.8	1.9	0.1	0.1	-0.1	-0.1
10	1.9	-0.5	6.2	1.0	-3.2	-8.2**	0.0	-0.2	-0.4	-0.2
11	0.5	0.2	2.3	-3.2	-4.2	1.7	-0.5	0.3	0.1	0.1
12	-1.6	0.1	-9.3	-3.7	4.8	0.8	-0.1	0.0	0.0	0.3
13	-0.4	0.7	-0.7	1.8	12.6	2.0	0.1	0.2	0.1	0.0
14	0.2	1.6	-3.9	-0.4	-11.3	-3.6**	-0.2	-0.2	-0.1	-0.3
15	-0.1	0.6	-2.9	-6.2	-13.6	0.8	0.0	-0.2	0.0	-0.1
16	1.6	0.8	-2.3	-2.4	-6.1	-9.0**	0.0	0.1	-0.2	-0.1
17	-0.1	0.5	6.0	-1.2	13.7	0.8	0.0	0.1	0.0	-0.1
18	0.0	1.3	11.4	4.0	-5.6	0.8	0.3	0.0	-0.2	0.0
19	-0.2	0.6	-17.1	-3.1	10.5	-1.6**	0.2	0.3	0.1	0.0
20	-0.2	0.8	0.9	3.3	-6.8	-0.7**	0.0	-0.2	0.0	0.3
21	-0.6	-1.6	4.5	-1.6	1.0	3.1	0.2	0.3	0.2	0.4
22	1.2	0.2	7.6	5.9	-5.1	0.8	-0.5	-0.3	-0.2	-0.1
23	2.8	-1.2	19.3	5.2	-0.8	-6.0**	-0.2	0.5	-0.2	-0.7*
24	1.8	-2.0	11.8	6.8	22.1	-0.7**	0.0	0.2	-0.1	-0.1
25	2.1	-1.9	4.2	7.7	-21.9	2.0	0.1	-0.3	-0.1	-0.2
26	-0.5	0.2	6.6	-7.8	13.1	2.1	0.1	0.0	0.1	0.2
27	-2.0	2.2	-3.0	3.0	-6.8	-1.5**	0.2	0.1	0.0	0.3
28	1.8	-2.3	9.4	7.2	-1.5	6.8	0.2	0.0	0.0	-0.3
29	2.4	-1.9	9.6	10.6	-14.9	1.1	-0.2	0.0	-0.2	-0.4
30	0.9	-0.8	-0.7	-3.2	-11.1	1.9	-0.4	0.5	0.2	-0.1
31	-0.1	-0.2	-5.2	-9.7	8.8	0.8	-0.1	0.1	0.0	0.2
32	-2.5	1.0	-11.1	-3.1	-17.0	2.8	0.1	0.0	0.1	0.3
33	1.2	0.0	-1.0	4.6	-16.7	-3.8**	0.0	-0.5	-0.1	-0.2
34	-0.4	0.3	9.2	3.3	17.9	-1.9**	-0.1	0.2	0.1	0.0
35	-2.0	-0.2	-5.9	-1.9	-13.6	0.6	0.1	-0.2	0.2	0.3
36	-2.8	2.1	-2.6	-3.3	10.2	-1.6**	0.0	0.2	-0.1	0.2
37	0.6	0.1	-8.6	-1.5	23.5	-2.8**	0.3	0.2	-0.1	-0.2
38	-1.5	-1.0	-2.8	-6.0	5.1	-2.9**	0.2	-0.2	0.0	0.0
39	0.5	1.9	-6.0	-1.1	1.8	1.9	-0.3	0.0	0.0	-0.5
40	-1.6	0.8	-1.8	0.3	5.0	0.8	0.1	0.2	-0.1	0.2
41	0.2	-0.4	-6.4	-2.8	2.4	-0.4**	-0.2	-0.4	-0.1	0.3
42	-0.4	0.1	2.1	2.0	29.0	2.0	0.1	0.1	0.0	0.1
43	-0.2	0.2	-2.1	1.0	-2.3	-2.0**	0.2	-0.3	0.1	-0.1
44	-0.6	-0.2	-29.4**	-9.2	-8.5	-1.7**	-0.4	0.1	0.0	0.0
45	-0.3	0.4	10.3	-3.5	-11.4	-0.9**	0.4	0.0	0.1	0.4
46	-1.3	0.5	-5.3	-5.5	-22.7	0.8	0.2	-0.3	0.0	0.4
47	1.4	-1.5	1.1	19.6**	30.7	2.0	0.0	-0.3	0.1	0.1
48	-0.7	-0.7	-10.1	-2.2	20.4	0.8	-0.1	0.1	0.1	0.3
49	-1.4	1.5	0.6	-2.8	-8.5	6.1	0.2	-0.3	0.0	0.3
50	-0.4	1.1	-0.1	-3.7	-22.0	-2.1**	-0.3	0.2	-0.2	0.0
51	-1.1	-0.7	-8.1	-6.9	12.2	4.3	0.4	-0.2	0.1	0.2
52	-1.6	0.6	-1.2	3.1	4.0	0.8	-0.1	0.1	0.0	-0.1

53	-1.5	1.4	-8.3	6.4	-2.9	-6.9**	-0.2	-0.2	-0.1	0.0
54	-1.3	2.1	-5.4	-2.8	-30.6	-3.9**	0.0	-0.4	0.1	0.3
55	-1.0	-1.5	9.7	0.5	3.4	0.9	-0.2	-0.2	0.2	0.1
56	-1.0	-0.8	-5.0	-6.8	-9.3	-0.4**	-0.1	0.2	0.1	0.1
57	-1.1	0.9	0.7	-6.4	18.9	-0.3**	0.0	0.0	0.2	0.0
58	-0.3	1.5	-2.3	-6.3	13.2	2.0	0.3	0.1	0.3	-0.2
59	0.2	-1.5	6.1	7.9	13.1	-2.4**	0.0	0.0	0.1	-0.2
60	0.1	-0.4	3.3	1.4	-12.5	-3.4**	-0.2	-0.3	0.0	0.1
61	-0.3	0.7	6.4	-1.7	-13.6	3.5	0.0	0.0	0.0	0.0
62	-0.3	1.4	-0.1	-3.0	-12.8	1.9	0.2	-0.4	0.0	-0.2
63	1.7	-1.2	0.4	1.9	12.0	-0.4**	0.3	0.0	-0.4	-0.1
64	0.8	0.9	-1.6	-0.9	-10.1	1.6	0.2	0.2	0.2	0.2
65	2.3	-2.7	24.1*	9.8	11.8	-3.2**	0.0	0.0	-0.3	-0.7

Appendix XII. Specific combining ability estimates with tester B for grain yield and yield related traits at Mabanga.

					SCA-Tester B					
LINE	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	-1.8	0.8	0.0	-3.1	23.8	-4.3**	0.1	-0.3	-0.1	0.1
2	0.0	-0.6	-3.5	-3.0	9.7	-3.5**	-0.1	-0.1	0.1	0.1
3	0.5	0.0	1.1	1.9	-1.1	0.6	-0.1	0.0	-0.1	-0.1
4	-0.4	-0.2	0.0	-0.9	-23.0	-0.7**	-0.2	-0.2	-0.1	-0.1
5	-0.1	0.3	-2.2	-2.2	11.2	-3.3**	0.2	0.0	0.0	0.5
6	0.0	0.8	10.5	6.5	-14.3	-1.7**	0.0	-0.1	-0.2	-0.4
7	0.1	0.5	-0.3	-0.3	-2.6	-0.8**	0.2	-0.1	0.1	0.2
8	-2.7	0.9	0.0	-1.0	-20.8	2.1	0.3	-0.2	0.1	0.2
9	-1.0	1.8	-3.3	-5.5	10.8	-1.9**	-0.1	-0.1	0.1	0.1
10	-1.9	0.5	-6.1	-0.9	3.2	8.2	0.0	0.2	0.4	0.2
11	-0.5	-0.2	-2.3	3.3	4.2	-1.7**	0.5	-0.3	-0.1	-0.1
12	1.6	-0.1	9.3	3.8	-4.8	-0.8**	0.1	0.0	0.0	-0.3
13	0.4	-0.7	0.7	-1.8	-12.6	-2.0**	-0.1	-0.2	-0.1	0.0
14	-0.2	-1.6	4.0	0.5	11.3	3.6	0.2	0.2	0.1	0.3
15	0.1	-0.6	2.9	6.3	13.6	-0.8**	0.0	0.2	0.0	0.1
16	-1.6	-0.8	2.3	2.5	6.1	9.0	0.0	-0.1	0.2	0.1
17	0.1	-0.5	-6.0	1.3	-13.7	-0.8**	0.0	-0.1	0.0	0.1
18	0.0	-1.3	-11.4	-4.0	5.6	-0.8**	-0.3	0.0	0.2	0.0
19	0.2	-0.6	17.2	3.2	-10.5	1.6	-0.2	-0.3	-0.1	0.0
20	0.2	-0.8	-0.8	-3.2	6.8	0.7	0.0	0.2	0.0	-0.3
21	0.6	1.6	-4.5	1.6	-1.0	-3.1**	-0.2	-0.3	-0.2	-0.4
22	-1.2	-0.2	-7.5	-5.8	5.1	-0.8**	0.5	0.3	0.2	0.1
23	-2.8	1.2	-19.3	-5.1	0.8	6.0	0.2	-0.5	0.2	0.7*
24	-1.8	2.0	-11.7	-6.8	-22.1	0.7	0.0	-0.2	0.1	0.1
25	-2.1	1.9	-4.2	-7.7	21.9	-2.0**	-0.1	0.3	0.1	0.2
26	0.5	-0.2	-6.6	7.9	-13.1	-2.1**	-0.1	0.0	-0.1	-0.2
27	2.0	-2.2	3.0	-2.9	6.8	1.5	-0.2	-0.1	0.0	-0.3
28	-1.8	2.3	-9.4	-7.2	1.5	-6.8**	-0.2	0.0	0.0	0.3
29	-2.4	1.9	-9.5	-10.6	14.9	-1.1**	0.2	0.0	0.2	0.4
30	-0.9	0.8	0.8	3.3	11.1	-1.9**	0.4	-0.5	-0.2	0.1
31	0.1	0.2	5.2	9.7	-8.8	-0.8**	0.1	-0.1	0.0	-0.2
32	2.5	-1.1	11.2	3.2	17.0	-2.8**	-0.1	0.0	-0.1	-0.3
33	-1.2	0.0	1.1	-4.5	16.7	3.8	0.0	0.5	0.1	0.2
34	0.5	-0.3	-9.1	-3.2	-17.9	1.9	0.1	-0.2	-0.1	0.0
35	2.0	0.1	5.9	2.0	13.6	-0.6**	-0.1	0.2	-0.3	-0.3
36	2.8	-2.1	2.6	3.4	-10.2	1.6	0.0	-0.2	0.1	-0.2
37	-0.6	-0.1	8.7	1.6	-23.5	2.8	-0.3	-0.2	0.1	0.2
38	1.5	1.0	2.9	6.0	-5.1	2.9	-0.2	0.2	0.0	0.0
39	-0.5	-1.9	6.0	1.1	-1.8	-1.9**	0.3	0.0	0.0	0.5
40	1.6	-0.8	1.9	-0.2	-5.0	-0.8**	-0.1	-0.2	0.1	-0.2
41	-0.2	0.4	6.4	2.8	-2.4	0.4	0.2	0.4	0.1	-0.3
42	0.4	-0.1	-2.1	-1.9	-29.0	-2.0**	-0.1	-0.1	0.0	-0.1
43	0.2	-0.2	2.2	-1.0	2.3	2.0	-0.2	0.3	-0.1	0.1
44	0.6	0.2	29.5**	9.3	8.5	1.7	0.4	-0.1	0.0	0.0
45	0.3	-0.4	-10.2	3.6	11.4	0.9	-0.4	0.0	-0.1	-0.4
46	1.3	-0.5	5.4	5.5	22.7	-0.8**	-0.2	0.3	0.0	-0.4
47	-1.4	1.5	-1.1	-19.4**	-30.7	-2.0**	0.0	0.3	-0.1	-0.1

48	0.7	0.7	10.1	2.3	-20.4	-0.8**	0.1	-0.1	-0.1	-0.3
49	1.4	-1.5	-0.5	2.9	8.5	-6.1**	-0.2	0.3	0.0	-0.3
50	0.4	-1.1	0.2	3.8	22.0	2.1	0.3	-0.2	0.2	0.0
51	1.1	0.7	8.1	6.9	-12.2	-4.3**	-0.4	0.2	-0.1	-0.2
52	1.6	-0.6	1.2	-3.0	-4.0	-0.8**	0.1	-0.1	0.0	0.1
53	1.5	-1.4	8.3	-6.4	2.9	6.9	0.1	0.2	0.1	0.0
54	1.3	-2.1	5.5	2.9	30.6	3.9	0.0	0.4	-0.1	-0.3
55	1.0	1.4	-9.6	-0.4	-3.4	-0.9**	0.2	0.2	-0.2	-0.1
56	1.0	0.8	5.0	6.9	9.3	0.4	0.1	-0.2	-0.1	-0.1
57	1.1	-0.9	-0.6	6.5	-18.9	0.3	0.0	0.0	-0.2	0.0
58	0.3	-1.5	2.4	6.4	-13.2	-2.0**	-0.3	-0.1	-0.3	0.2
59	-0.2	1.5	-6.0	-7.8	-13.1	2.4	0.0	0.0	-0.1	0.2
60	-0.1	0.4	-3.3	-1.4	12.5	3.4	0.2	0.3	0.0	-0.1
61	0.4	-0.7	-6.3	1.8	13.6	-3.5**	0.0	0.0	0.0	0.0
62	0.3	-1.5	0.1	3.0	12.8	-1.9**	-0.2	0.4	0.0	0.2
63	-1.7	1.2	-0.4	-1.8	-12.0	0.4	-0.3	0.0	0.4	0.1
64	-0.8	-0.9	1.7	1.0	10.1	-1.6**	-0.2	-0.2	-0.2	-0.2
65	-2.3	2.6	-24.7*	-9.8	-11.8	3.2	0.0	0.0	0.3	0.7

Appendix XIII. GCA for grain yield and yield related traits at Shikusa.

	GCA									
LINE	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	-0.9	-0.2	-0.9	-3.0	20.6	3.8	-0.4	0.0	0.4	0.1
2	-0.6	-1.8	0.7	-13.3	-6.9	-4.2**	-0.5	0.2	-0.1	0.0
3	1.0	0.6**	16.1	15.4	-8.5	-5.0**	-0.5	-0.2	0.0	-0.1
4	0.4	0.8	15.2	16.2	-5.1	-5.0**	-0.5	-0.3	-0.4	-0.3
5	-0.3	0.4	-5.1	-9.4	-0.4	1.8	0.6	0.3	0.1	0.1
6	0.1	-2.0**	10.6	6.7	-0.4	-4.6**	-0.4	0.1	-0.4	0.0
7	-0.9	2.3**	5.2	-0.3	-13.4	-6.4**	0.3	0.1	0.3	0.0
8	-0.7	0.1**	-28.2*	-19.9	16.1	5.3	0.5	-0.1	0.9*	0.5**
9	-2.5*	1.6**	3.9	3.1	-3.1	4.3	0.7	-0.3	0.5	0.4*
10	-1.8	-0.4	-19.0	-17.6	-1.7	13.8	-0.4	0.6*	0.4	0.4*
11	0.2	2.6	-9.4	-11.5	-6.6	-0.4**	0.7	-0.1	0.0	0.3
12	1.6	-1.5	12.2	10.4	21.7	-6.3**	-0.4	0.1	-0.4	-0.2
13	0.2	-1.9	-0.1	-0.9	-4.2	-4.0**	-0.2	-0.3	-0.1	0.0
14	0.0	1.3	-8.6	8.0	-14.5	0.2	1.22*	0.1	-0.5	0.3
15	-0.1	-3.7	-16.6	-21.4	-12.8	-5.6**	-0.5	0.3	-0.5	0.2
16	-0.2	-0.9	-19.3	-14.6	-10.1	-0.7**	-0.2	0.2	0.0	0.0
17	1.1	-1.6	11.4	10.2	0.1	-0.9**	0.0	0.1	-0.3	-0.2
18	0.5	1.9	-19.2	-0.4	10.5	-6.5**	-0.5	0.1	0.1	0.0
19	1.2	-0.4	0.2	3.8	5.8	-5.8**	-0.3	-0.1	0.5	-0.2
20	-0.6	0.0	2.5	4.1	-12.6	-6.2**	-0.2	-0.1	-0.1	-0.1
21	-0.2	-0.3	-17.6	-7.0	4.6	1.2	-0.6	-0.3	0.1	-0.1
22	-0.8	-0.1	3.2	7.9	-13.0	-0.7**	0.9	-0.3	0.3	0.5**
23	-1.9	2.7	-24.4*	-22.3	-11.7	16.7	0.2	0.3	0.1	0.2
24	-1.7	0.7	-21.9	-19.4	13.1	7.7	-0.3	-0.5	0.6	0.4*
25	-1.7	1.7	-15.3	-14.0	-7.2	10.4	1.0*	-0.4	0.3	0.2
26	1.5	0.7	14.3	20.4	7.4	-4.3**	0.2	-0.1	-0.5	-0.4
27	0.4	1.5	4.4	9.7	0.0	-0.3**	0.3	0.1	-0.5	-0.4
28	-0.5	-0.3	-3.6	-17.5	6.6	0.02*	0.2	0.2	0.4	0.0
29	-2.5*	1.2	-3.7	-12.1	-19.1	21.8***	-0.3	-0.3	0.3	-0.2
30	-1.6	0.3	-2.7	0.0	-13.6	2.1	0.7	-0.1	0.4	-0.1
31	0.6	-0.2	13.5	9.1	-5.0	-6.9**	1.0*	0.3	0.1	0.1
32	-1.8	0.0	-2.0	-12.6	0.5	-2.6**	-0.3	0.3	0.4	0.0
33	-1.3	-2.3	-11.5	-24.5*	-12.4	5.6	0.2	0.2	0.0	-0.1
34	1.9	0.4	0.5	4.4	-4.5	-0.1**	-0.4	-0.4	-0.4	0.0
35	2.5*	1.2	17.8	25.8*	-2.7	0.4	-0.5	-0.2	-0.8*	-0.3
36	0.2	-1.9	-5.5	-6.0	-15.6	4.7	-0.5	-0.3	-0.3	-0.4
37	1.0	-0.8	0.1	4.0	-9.4	-1.0**	0.1	0.1	-0.3	-0.2
38	2.0	-1.5	15.3	11.1	8.7	-3.9**	-0.3	-0.3	-0.1	-0.1

39	-0.3	-5.5***	-21.7	-17.2	-0.6	-4.9**	0.2	0.2	-0.3	0.0
40	1.2	0.6	-0.5	5.6	-13.6	-6.4**	-0.6	0.2	-0.3	-0.1
41	-0.2	-0.4	22.4	6.1	15.0	1.6	1.3**	0.2	0.1	-0.1
42	-1.2	0.2	-4.0	-1.4	22.2	-7.6**	-0.2	0.0	0.1	0.0
43	0.0	-0.4	-0.7	3.2	-1.9	-1.6**	0.6	0.5	-0.1	0.2
44	0.8	-0.7	-6.9	15.8	-7.3	-1.1**	0.7	0.0	0.1	0.2
45	2.6*	0.0	14.7	18.2	4.0	1.6	-0.2	-0.3	-0.8*	-0.2
46	-0.3	0.0	3.7	2.3	-1.1	-9.3**	0.1	0.0	-0.1	0.0
47	1.5	1.2	11.0	19.1	9.7	-5.0**	-0.5	0.0	-0.4	-0.2
48	0.0	-0.3	16.6	13.1	31.6**	-1.5**	0.5	-0.1	0.75*	0.0
49	-0.6	-0.8	-4.2	-14.8	-9.7	1.1	-0.1	-0.3	0.1	0.2
50	0.5	1.2	23.1	9.3	-12.6	1.3	-0.2	0.3	-0.1	0.0
51	1.1	-1.4	-2.7	4.4	-4.3	-6.6**	-0.4	0.1	-0.6	-0.1
52	1.1	-0.3	3.0	3.6	4.0	2.8	-0.4	0.3	-0.3	-0.1
53	1.0	0.9	18.0	15.8	17.5	3.8	-0.6	0.1	-0.1	-0.1
54	0.7	0.2	8.5	5.0	11.1	0.7	-0.5	0.4	0.3	-0.1
55	0.2	0.4	-3.6	-1.0	30.5**	11.1	0.3	0.1	0.4	0.0
56	0.3	0.7**	-13.4	-3.6	1.3	5.2	-0.1	-0.2	-0.1	-0.1
57	1.3	1.5	10.8	17.4	16.3	-5.9**	-0.1	0.1	0.0	0.0
58	1.4	0.7	6.4	6.0	3.6	-1.1**	-0.4	-0.3	-0.4	-0.2
59	-0.5	1.4	-2.2	0.5	-5.8	1.9	0.0	-0.2	0.1	0.0
60	1.2	-0.9**	14.2	-0.2	-13.6	-3.2**	0.1	-0.2	-0.6	-0.1
61	0.0	-0.6**	15.6	1.5	-7.8	-0.9**	-0.2	0.0	0.0	-0.1
62	-1.8	-1.8**	9.8	-3.2	-8.7	2.8	0.0	0.8**	0.3	0.0
63	-1.5	-0.1**	-2.5	-9.9	2.7	-1.6**	-0.2	-0.2	0.4	-0.1
64	-0.6	1.4**	-4.0	2.7	1.2	8.2	0.3	-0.4	0.3	0.0
65	-1.7	3.9**	-24.0*	-22.0	10.0	-2.7**	0.3	-0.2	0.6	0.3

Appendix XIV. Specific combining ability estimates with tester A for grain yield and yield related traits at Shikusa.

					SCA-Tester A				
LINE	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	-0.1	-0.6	-4.2	-2.8	11.5	2.0	0.2	0.0	0.2	0.3
2	-1.9	0.0	-1.6	7.1	-1.9	1.9	0.3	-0.3	-0.1	0.0
3	-0.1	1.2	-0.4	-2.3	-4.8	2.5	0.3	-0.4	-0.2	-0.1
4	-1.1	0.9	-4.4	-3.2	-1.8	3.0	0.3	0.3	0.2	0.1
5	-1.1	0.4	-0.7	0.3	-4.8	-1.3**	0.8	0.3	0.2	-0.1
6	0.6	0.0	-7.8	-0.1	-0.5	-2.0**	0.2	0.0	0.2	0.0
7	0.2	0.0	4.5	-0.8	-10.0	-1.1**	-0.4	-0.1	-0.4	-0.2
8	-0.9	-1.9	20.3	6.7	12.3	3.8	-0.4	0.3	-0.3	-0.2
9	0.6	-1.4	2.4	2.4	-15.3	6.6	-0.6	0.1	0.1	-0.1
10	1.5	-1.1	5.0	2.3	4.5	-1.3**	0.2	-0.1	-0.6	-0.1
11	0.0	0.3	6.1	-1.1	-5.0	-1.5**	-0.8	0.2	-0.4	0.0
12	-0.8	-1.5	-2.8	-3.9	23.0	2.2	0.1	-0.2	0.5	0.3
13	-0.4	-0.5	-2.1	1.8	2.9	1.5	0.1	-0.2	0.2	0.0
14	-0.5	1.0	-7.4	-2.9	-8.7	-4.1**	-0.9	-0.2	0.1	0.0
15	-0.3	-0.4	1.9	-1.8	-9.2	1.1	0.3	-0.1	-0.2	-0.1
16	2.1	-0.9	6.2	7.2	-7.9	-5.0**	0.1	0.0	-0.7	-0.2
17	0.0	0.6	-5.3	-2.8	4.2	4.8	-0.1	0.1	0.3	0.0
18	0.8	1.3	9.7	3.3	3.7	0.1*	0.3	-0.1	-0.1	-0.2
19	0.2	-0.4	1.4	6.3	14.1	1.4	0.2	-0.2	0.1	-0.3
20	-0.1	-0.7	-2.8	6.6	-8.1	2.5	0.1	-0.2	-0.1	0.1
21	-1.2	0.2	1.6	2.2	5.9	1.9	0.3	0.0	0.5	0.1
22	-1.0	0.6	3.3	6.0	-11.9	-2.8**	-1.2	0.0	-0.2	-0.2
23	2.3	-2.2	29.1**	12.3	-8.4	-20.6**	-0.4	0.3	-1.1*	-0.4
24	1.7	-1.1	10.1	7.2	6.4	0.3	0.0	0.1	-0.3	-0.1
25	1.7	-0.4	8.7	3.0	-4.7	-6.3**	0.3	-0.2	-0.4	-0.1
26	-0.9	0.6	0.0	-2.0	13.1	4.5	1.0	0.0	0.3	0.1
27	0.0	1.2	-4.3	-1.1	5.0	3.3	1.0	-0.1	0.1	0.1
28	2.0	-1.2	0.7	0.8	6.9	-3.8**	-0.4	0.0	-0.3	-0.2
29	1.7	-1.4	7.5	4.3	-12.7	-14.1**	0.0	0.0	-0.7	-0.2
30	1.6	0.1	3.7	2.9	-7.1	1.8	-0.8	0.1	-0.3	-0.1
31	-1.2	0.0	-14.0	-11.3	1.2	-0.3**	-1.2	0.5	0.2	0.0
32	-0.6	1.3	-6.0	-6.8	0.7	6.9	0.2	0.1	0.5	0.5*
33	-0.1	-1.2	2.2	-0.4	-17.3	-2.3**	1.1	0.2	0.1	-0.1

34	0.2	0.9	0.5	4.5	-8.5	-3.5**	0.3	0.0	-0.1	0.0
35	0.9	-0.1	-2.1	2.0	0.1	5.1	0.3	-0.1	0.1	0.2
36	-0.6	0.4	-2.2	-2.1	-7.9	-4.5**	0.2	0.0	-0.2	0.2
37	0.1	0.2	-14.1	-3.9	-1.2	3.4	-0.4	0.1	0.1	0.0
38	-0.7	-0.3	-8.0	-10.3	11.8	-2.9**	0.0	0.0	0.2	0.1
39	-0.9	1.1	0.2	4.0	3.0	3.9	-0.5	0.2	-0.2	0.0
40	0.1	-0.1	-2.4	-9.4	-9.1	1.3	0.3	0.1	-0.2	0.2
41	-0.3	0.3	-7.0	-1.9	16.5	9.5	-0.9	0.2	0.7	0.1
42	1.5	-0.7	-1.3	2.3	24.0	-3.1**	0.5	0.1	0.7	0.0
43	0.4	0.2	-1.2	0.2	0.7	-1.8**	-0.7	0.0	-0.1	0.1
44	0.4	-0.5	-8.7	-8.3	-6.3	1.7	0.6	-0.2	-0.3	-0.1
45	0.9	0.4	-0.3	0.4	-8.7	-3.8**	0.0	0.2	0.1	0.0
46	-1.9	0.1	0.3	-2.1	-1.7	1.5	-0.2	0.2	-0.1	0.0
47	1.1	-0.1	-0.1	-3.1	13.2	2.2	0.4	0.0	-0.1	0.0
48	-0.5	0.2	-14.5	-12.2	3.2	1.2	-0.1	-0.1	0.1	0.3
49	-1.7	1.8	-0.9	-4.6	-3.4	2.9	0.1	-0.1	0.5	-0.1
50	0.5	0.3	-6.7	-2.1	-9.7	10.1	0.1	-0.67*	-0.1	0.0
51	-1.1	0.1	-9.4	-8.1	-2.6	-0.7**	0.4	-0.2	0.5	0.1
52	0.3	-0.5	0.3	5.9	2.5	-3.4**	0.3	0.3	-0.2	-0.1
53	-0.8	0.3	-1.6	-1.0	-0.3	-7.3**	0.2	-0.1	-0.1	0.1
54	-1.7	0.7	-8.4	2.7	-1.7	-4.4**	0.4	0.4	0.1	0.1
55	-0.1	0.4	-2.2	-1.1	27.2*	17.7	-0.7	-0.2	0.7	0.0
56	1.0	1.0	0.5	0.5	-1.3	-1.9**	-0.1	-0.4	-0.1	-0.1
57	-0.3	0.1	4.4	-5.5	14.4	1.4	-0.1	-0.1	0.3	0.0
58	-0.9	0.5	-6.4	0.9	6.0	-0.5**	0.2	-0.3	0.5	0.0
59	-1.1	0.9	1.2	2.7	-4.3	-5.8**	0.1	0.1	-0.1	0.0
60	0.0	1.5	3.0	3.2	-11.9	0.7	-0.3	0.1	-0.1	0.1
61	-1.1	0.2	6.5	0.4	-4.7	5.5	-0.1	0.0	0.1	0.1
62	-0.8	1.4	3.7	3.9	-3.0	5.8	-0.2	0.4	0.3	0.3
63	1.0	-0.8	-4.3	-0.5	-12.1	-3.6**	0.5	-0.3	-0.1	-0.1
64	-1.0	1.2	-5.3	-7.2	4.8	-2.1**	-0.5	-0.2	0.1	0.3
65	2.9	-4.0**	25.3*	11.8	0.2	0.4	-0.5	0.4	-0.6	-0.5*

Appendix XV. Specific combining ability estimates with tester B for grain yield and yield related traits at Shikusa.

	SCA-Tester B									
LINE	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	0.1	0.6	4.2	2.8	-11.3	-2.1**	-0.2	0.0	-0.2	-0.3
2	2.0	0.0	1.6	-7.0	2.1	-1.9**	-0.3	0.3	0.1	0.0
3	0.1	-1.2	0.4	2.3	4.9	-2.5**	-0.3	0.4	0.2	0.1
4	1.1	-0.9	4.4	3.2	2.0	-3**	-0.3	-0.3	-0.2	-0.1
5	1.2	-0.4	0.7	-0.3	4.9	1.3	-0.8	-0.3	-0.2	0.1
6	-0.6	0.0	7.8	0.2	0.6	2.0	-0.2	0.0	-0.2	0.0
7	-0.2	0.0	-4.5	0.9	10.1	1.1	0.4	0.1	0.4	0.2
8	0.9	1.9	-20.3	-6.7	-12.2	-3.8**	0.4	-0.3	0.3	0.2
9	-0.6	1.4	-2.4	-2.4	15.4	-6.7**	0.6	-0.1	-0.1	0.1
10	-1.5	1.1	-5.0	-2.3	-4.4	13.0	-0.2	0.1	0.6	0.1
11	0.0	-0.3	-6.1	1.2	5.1	1.4	0.8	-0.2	0.4	0.0
12	0.9	1.4	2.8	3.9	-22.9	-2.2**	-0.1	0.2	-0.5	-0.3
13	0.4	0.5	2.1	-1.7	-2.8	-1.6**	-0.1	0.2	-0.2	0.0
14	0.6	-1.0	7.4	2.9	8.9	4.1	0.9	0.2	-0.1	0.0
15	0.3	0.4	-1.9	1.8	9.3	-1.1**	-0.3	0.1	0.2	0.1
16	-2.1	0.8	-6.2	-7.2	8.1	5.0	-0.1	0.0	0.7	0.2
17	0.0	-0.6	5.3	2.8	-4.1	-4.8**	0.1	-0.1	-0.3	0.0
18	-0.8	-1.3	-9.7	-3.3	-3.6	-0.1**	-0.3	0.1	0.1	0.2
19	-0.2	0.4	-1.4	-6.3	-13.9	-1.4**	-0.2	0.2	-0.1	0.3
20	0.1	0.7	2.8	-6.6	8.3	-2.6**	-0.1	0.2	0.1	-0.1
21	1.2	-0.2	-1.6	-2.2	-5.7	-1.9**	-0.3	0.0	-0.5	-0.1
22	1.0	-0.6	-3.3	-5.9	12.1	2.8	1.2	0.0	0.2	0.2
23	-2.3	2.1	-29.1**	-12.2	8.6	20.6	0.4	-0.3	1.1*	0.4
24	-1.7	1.1	-10.1	-7.2	-6.2	-0.3**	0.0	-0.1	0.3	0.1
25	-1.7	0.4	-8.6	-3.0	4.8	6.2	-0.3	0.2	0.4	0.1
26	1.0	-0.6	0.0	2.1	-13.0	-4.6**	-1.0	0.0	-0.3	-0.1
27	0.0	-1.2	4.3	1.1	-4.8	-3.3**	-1.0	0.1	-0.1	-0.1
28	-1.9	1.2	-0.7	-0.8	-6.7	3.8	0.4	0.0	0.3	0.2
29	-1.7	1.4	-7.5	-4.3	12.8	14.1	0.0	0.0	0.7	0.2
30	-1.6	-0.2	-3.7	-2.8	7.2	-1.8**	0.8	-0.1	0.3	0.1
31	1.2	0.0	14.0	11.4	-1.0	0.2	1.2	-0.5	-0.2	0.0
32	0.6	-1.3	6.0	6.9	-0.6	-6.9**	-0.2	-0.1	-0.5	-0.5*
33	0.1	1.1	-2.2	0.5	17.4	2.3	-1.1	-0.2	-0.1	0.1
34	-0.2	-0.9	-0.5	-4.4	8.6	3.5	-0.3	0.0	0.1	0.0
35	-0.9	0.1	2.1	-1.9	0.1	-5.1**	-0.3	0.1	-0.1	-0.2
36	0.6	-0.4	2.2	2.1	8.0	4.4	-0.2	0.0	0.2	-0.2
37	-0.1	-0.2	14.1	3.9	1.3	-3.5**	0.4	-0.1	-0.1	0.0

38	0.7	0.3	8.0	10.3	-11.6	2.8	0.0	0.0	-0.2	-0.1
39	0.9	-1.1	-0.2	-3.9	-2.8	-4.0**	0.5	-0.2	0.2	0.0
40	-0.1	0.1	2.4	9.5	9.3	-1.3**	-0.3	-0.1	0.2	-0.2
41	0.3	-0.3	7.0	2.0	-16.4	-9.5**	0.9	-0.2	-0.7	-0.1
42	-1.5	0.7	1.3	-2.3	-23.9	3.0	-0.5	-0.1	-0.7	0.0
43	-0.3	-0.2	1.2	-0.2	-0.6	1.7	0.7	0.0	0.1	-0.1
44	-0.4	0.4	8.7	8.4	6.4	-1.7**	-0.6	0.2	0.3	0.1
45	-0.9	-0.4	0.3	-0.3	8.8	3.7	0.0	-0.2	-0.1	0.0
46	1.9	-0.1	-0.3	2.1	1.8	-1.5**	0.2	-0.2	0.1	0.0
47	-1.0	0.1	0.1	3.1	-13.1	-2.9**	-0.4	0.0	0.1	0.0
48	0.5	-0.2	14.5	12.2	-3.1	-1.3**	0.1	0.1	-0.1	-0.3
49	1.7	-1.8	0.9	4.7	3.5	-2.9**	-0.1	0.1	-0.5	0.1
50	-0.4	-0.3	6.7	2.2	9.8	-10.1**	-0.1	0.7*	0.1	0.0
51	1.1	-0.1	9.4	8.1	2.7	0.7	-0.4	0.2	-0.5	-0.2
52	-0.3	0.5	-0.3	-5.9	-2.3	3.4	-0.3	-0.3	0.2	0.1
53	0.8	-0.3	1.6	1.1	0.4	7.3	-0.2	0.1	0.1	-0.1
54	1.8	-0.7	8.4	-2.6	1.8	4.4	-0.4	-0.4	-0.1	-0.1
55	0.2	-0.4	2.2	1.1	-27*	-17.7**	0.7	0.2	-0.7	0.0
56	-1.0	-1.0	-0.5	-0.4	1.4	1.9	0.1	0.4	0.1	0.1
57	0.3	-0.1	-4.4	5.5	-14.3	-1.4**	0.1	0.1	-0.3	0.0
58	0.9	-0.5	6.4	-0.9	-5.8	0.4	-0.2	0.3	-0.5	0.0
59	1.1	-0.9	-1.2	-2.7	4.5	5.7	-0.1	-0.1	0.1	0.0
60	0.0	-1.5	-3.0	-3.1	12.0	-0.7**	0.3	-0.1	0.1	-0.1
61	1.1	-0.2	-6.5	-0.4	4.8	-5.5**	0.1	0.0	-0.1	-0.1
62	0.8	-1.4	-3.7	-3.8	3.2	-5.8**	0.2	-0.4	-0.3	-0.3
63	-1.0	0.8	4.3	0.6	12.2	3.5	-0.5	0.3	0.1	0.1
64	1.0	-1.3	5.3	7.2	-4.6	2.1	0.5	0.2	-0.1	-0.3
65	-2.9	4.0**	-25.3*	-11.8	-0.1	-0.4**	0.5	-0.4	0.6	0.5*

Appendix XVI. GCA estimates for grain yield and yield related traits across locations

	GCA									
LINE	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	-0.2	-0.7	-1.2	-4.4	30.3*	2.2	-0.2	-0.1	0.2	0.1
2	0.2	-2.4	-3.4	-11.1	-16.8	-4.1	-0.4	0.5*	-0.2	-0.2
3	0.8	0.1	15.3	12.0	-6.9	-6.6	-0.3	0.1	0.0	0.0
4	1.5	1.5	12.4	14.1	5.9	-3.3	-0.4	-0.1	-0.2	-0.2
5	0.0	-0.2	-5.2	-10.9	-6.4	8.2	0.0	0.8***	0.2	0.0
6	-0.1	-1.5	9.1	6.3	10.6	-1.0	-0.2	0.2	0.0	0.0
7	0.0	2.2	9.8	3.9	-1.3	-5.2	0.4	0.0	0.0	0.0
8	-2.2	-0.2	-29.4*	-22.9*	7.3	3.2	0.6	0.0	0.6*	0.6**
9	-1.7	1.4	4.4	2.4	11.7	1.2	0.4	-0.1	0.4	0.3
10	-1.8	-0.9	-19.8	-17.4	-1.8	6.8	0.0	0.2	0.3	0.3
11	0.4	2.7	-12.0	-11.7	-11.0	5.9	0.2	-0.1	0.1	0.1
12	1.8	-0.5	12.6	9.0	15.2	-2.2	-0.4	-0.1	-0.3	-0.3
13	0.0	-2.4	1.5	-1.0	5.7	-5.7	-0.2	0.1	-0.1	0.0
14	-0.4	0.7	-10.1	6.6	-20.3	-2.3	1.7**	-0.1	-0.3	0.2
15	0.1	-3.8*	-13.6	-20.6	-22.4	-4.0	-0.4	0.3	-0.3	-0.3
16	-0.3	-1.4	-15.6	-13.9	-13.1	4.9	-0.1	0.0	0.1	0.1
17	1.3	-0.9	8.2	10.6	12.1	-4.6	-0.5	-0.1	0.0	-0.1
18	-0.4	3.1	-18.9	-1.3	7.8	-5.4	-0.5	-0.2	0.2	0.2
19	0.9	-0.6	-0.3	5.9	1.5	-5.3	-0.2	-0.2	0.0	-0.2
20	0.6	-0.3	0.8	6.5	-8.8	-4.0	-0.3	-0.2	-0.3	-0.2
21	0.2	-0.1	-12.7	-3.7	4.0	-2.2	-0.5	-0.5*	0.1	-0.1
22	-0.2	-0.5	1.2	8.2	-17.1	-0.5	0.6	-0.2	0.1	0.2
23	-2.3*	2.5	-27.1*	-25.6*	-12.5	10.6*	0.7	0.1	0.3	0.4*
24	-2.3*	0.4	-20.6	-18.9	7.6	7.8	-0.3	-0.3	0.5	0.3
25	-2.2	2.7	-15.1	-7.1	-1.0	11.1*	0.3	-0.3	0.3	0.2
26	1.3	0.2	9.9	17.1	4.2	-1.3	0.0	-0.3	-0.2	-0.3
27	1.0	2.2	-1.4	3.7	-11.2	-2.3	-0.3	0.0	-0.5	-0.3
28	-1.7	0.2	-8.3	-15.4	16.7	2.4	0.3	0.0	0.5*	0.0
29	-2.5*	1.3	-3.4	-8.7	-23.9	14.8**	0.2	-0.2	0.3	-0.1
30	-1.3	0.5	3.1	0.4	-6.4	-0.9	0.6	0.0	0.2	-0.1
31	0.7	-0.4	16.2	9.6	12.4	-7.0	0.78*	0.1	0.0	0.1
32	-1.8	0.6	0.5	-8.2	19.8	0.0	-0.5	0.4	0.3	0.3
33	-0.7	-3.7*	-9.4	-20.2	-15.8	9.0	-0.1	0.4	0.0	0.0
34	1.3	-0.2	2.4	7.2	0.5	1.8	-0.2	-0.3	-0.2	0.0
35	1.9	3.0	20.0	23.7*	-15.6	-0.4	-0.6	-0.3	-0.4	-0.4*
36	0.0	-1.8	-11.7	-10.7	-17.1	10.3*	-0.3	0.0	-0.1	-0.3
37	0.8	-1.2	1.4	1.1	-3.1	-2.1	-0.4	0.0	-0.2	-0.2

38	1.0	-1.3	15.4	7.3	3.6	0.2	-0.1	-0.1	-0.1	-0.2
39	0.1	-4.6**	-19.4	-16.2	-2.7	-5.8	0.6	0.1	-0.2	0.0
40	1.1	2.2	4.1	10.9	-5.2	-6.1	-0.4	0.0	-0.3	0.0
41	0.4	0.1	17.8	9.2	23.7	-3.8	0.4	0.47*	0.0	0.1
42	-0.7	0.3	-1.3	0.5	16.5	-3.7	-0.4	0.3	0.1	0.1
43	1.0	-0.8	2.3	3.9	-5.6	-2.6	0.3	0.2	-0.2	0.1
44	1.5	-1.4	-1.9	16.1	-14.2	-0.8	0.3	-0.2	-0.2	0.1
45	2.7*	0.7	11.4	8.4	10.8	6.2	-0.5	-0.2	-0.4	-0.2
46	-0.8	1.4	4.4	4.8	-11.0	-7.9	0.1	0.2	-0.1	-0.1
47	1.0	1.2	9.5	23.4*	9.6	-4.6	-0.2	-0.2	-0.2	0.0
48	-0.4	0.6	18.0	10.7	15.8	-1.6	0.6	-0.1	0.5*	0.1
49	0.4	-1.6	-5.4	-16.3	-11.1	3.1	0.1	0.3	-0.2	0.0
50	-0.2	1.0	20.9	4.2	-23.5	2.6	0.2	0.1	-0.1	-0.1
51	0.3	-1.4	-3.5	5.8	-5.3	-4.3	-0.6	0.2	-0.3	-0.2
52	1.0	-1.3	0.0	2.9	-3.1	0.3	0.1	-0.1	-0.2	-0.2
53	1.0	1.6	20.5	19.4	28.7*	0.4	-0.5	0.0	0.0	0.0
54	0.4	0.2	6.2	3.6	15.6	-2.0	-0.3	0.2	0.2	-0.2
55	0.0	0.9	-5.8	-2.1	34.2*	0.4	0.5	0.0	0.2	0.2
56	0.3	0.1	-12.6	-6.6	-0.7	4.0	0.1	-0.1	0.1	0.0
57	0.6	2.5	13.4	16.5	17.5	-6.2	0.1	0.1	-0.2	0.1
58	0.7	0.2	3.5	6.2	-5.7	-3.4	0.1	0.3	-0.2	-0.1
59	-0.9	1.3	-3.2	-2.2	-0.7	2.8	-0.2	-0.5	0.2	0.0
60	1.3	-2.6	14.7	-2.4	-16.8	1.6	0.3	-0.1	-0.3	-0.2
61	0.0	-2.1	16.6	2.6	-13.2	-1.0	0.1	-0.1	-0.2	0.0
62	-1.0	-1.5	12.4	-2.2	-12.4	0.5	0.0	0.6*	0.1	0.1
63	-0.9	-0.4	-0.7	-4.0	6.7	-5.1	0.0	-0.1	0.0	0.3
64	-0.2	0.7	-4.5	-0.6	-2.3	5.0	0.1	-0.3	0.3	-0.1
65	-2.5*	2.0	-22.3	-18.7	9.9	1.7	0.0	-0.2	0.5	0.3

Appendix XVII. Specific combining ability estimates with Tester A for grain yield and yield related traits across locations.

	SCA TESTER-A									
LINE	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	0.5	-0.4	-0.4	1.0	-6.8	-1.4	-0.1	0.1	0.1	0.0
2	-1.0	0.5	-1.0	5.8	-11.2	3.4	0.2	-0.1	-0.2	0.0
3	-0.8	0.8	0.8	1.5	-2.8	1.7	0.0	0.0	0.1	0.1
4	-0.3	0.3	-0.3	0.9	12.5	3.1	0.1	0.2	0.2	0.2
5	-0.3	0.1	2.4	1.1	-14.9	0.1	0.1	-0.1	0.0	-0.2
6	0.3	-0.8	-7.5	-4.3	10.1	-1.6	0.0	0.1	0.2	0.1
7	0.1	-0.3	1.8	0.3	-10.7	-0.6	-0.4	0.0	-0.2	-0.2
8	1.4	-2.1*	10.0	6.5	14.8	0.3	-0.3	0.3*	-0.2	-0.3
9	0.9	-1.2	1.0	3.9	-3.6	2.4	-0.4	0.2	-0.1	-0.1
10	1.7	-0.8	5.2	2.2	6.2	-9.1**	-0.1	-0.2	-0.3	-0.1
11	0.6	0.4	2.9	-2.2	-3.9	-0.4	-0.3	0.2	-0.3	0.0
12	-0.9	-0.9	-4.4	-3.0	13.5	-1.4	0.0	-0.1	0.2	0.3
13	-0.4	0.1	-0.2	1.0	9.4	2.3	0.2	-0.1	0.2	0.1
14	-0.3	1.1	-7.5	-4.1	-10.6	-0.7	-0.4	-0.2	0.0	-0.1
15	0.1	0.0	-1.6	-4.9	-12.7	0.6	0.2	-0.1	-0.1	-0.1
16	1.6	0.0	3.6	4.9	-3.4	-6.4	0.1	0.1	-0.4	-0.1
17	-0.3	-0.1	-1.4	-3.6	5.9	4.0	0.2	0.2	0.2	0.0
18	0.3	1.4	11.6	5.0	3.4	0.8	0.3	-0.1	-0.1	-0.1
19	-0.1	0.1	-4.5	1.0	11.2	0.4	0.3	0.0	0.2	0.1
20	-0.5	0.0	0.1	5.5	-1.7	1.1	0.0	-0.1	0.1	0.0
21	-0.8	-0.7	-1.0	-2.8	10.3	2.2	0.2	0.1	0.2	0.41*
22	0.5	0.5	2.2	5.6	-9.8	-1.5	-0.8**	-0.1	-0.2	-0.1
23	3.0**	-2.1*	25.4***	9.4*	-2.9	-12.2***	-0.3	0.1	-0.7***	-0.6**
24	1.5	-1.5	13.6*	9.5*	14.9	-4.5	0.0	0.1	-0.2	-0.2
25	1.9*	-0.6	7.3	1.2	-5.6	-0.8	0.0	-0.2	-0.2	-0.1
26	-0.5	0.6	-0.6	-6.5	13.8	3.0	0.51*	0.1	0.2	0.2
27	-0.7	1.3	-3.5	0.1	-1.5	0.9	0.6*	-0.1	0.1	0.2
28	1.5	-1.7*	2.5	2.3	7.1	-0.7	-0.1	-0.2	-0.3	-0.1
29	2.0*	-1.9*	9.6	7.2	-14.3	-5.0	-0.3	-0.1	-0.6**	-0.6**
30	1.0	-0.4	3.9	-0.1	-4.5	3.0	-0.5	0.3*	-0.2	-0.2

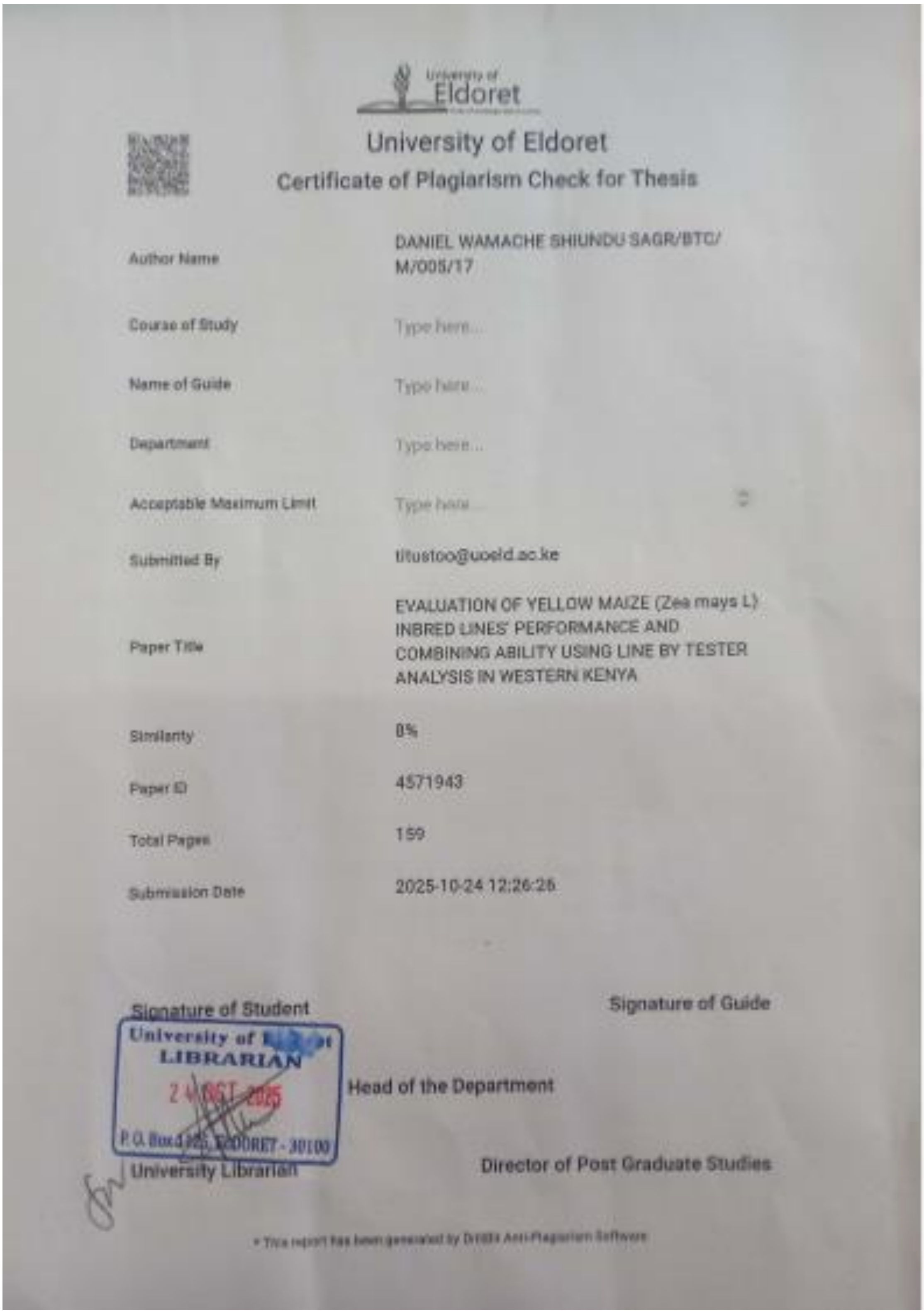
31	-0.6	0.0	-8.9	-10.2*	1.3	2.2	-0.5	0.1	0.1	0.0
32	-0.9	0.3	-10.5	-5.0	-9.3	5.6	0.3	0.0	0.3	0.3
33	-0.1	-0.1	1.0	2.0	-12.6	-0.7	0.4	-0.2	-0.1	0.0
34	0.0	0.8	4.8	5.2	3.7	-3.3	0.0	0.2	0.1	0.1
35	-0.7	-0.1	-0.7	1.3	-7.9	4.0	0.4	-0.1	0.1	0.2
36	-1.9*	0.7	-2.4	-2.9	-7.5	-0.6	0.2	0.2	-0.1	0.2
37	0.4	0.3	-9.2	-5.1	5.7	0.5	0.2	-0.1	0.1	-0.2
38	-0.8	-0.7	-4.9	-7.1	11.6	-4.3	-0.1	0.1	0.2	0.1
39	0.1	0.6	-7.9	-2.0	1.3	2.0	-0.4	0.1	0.1	-0.1
40	-0.2	0.5	-1.5	-4.0	0.5	1.7	0.1	-0.1	-0.2	0.2
41	-0.2	-0.3	-12.8	-4.3	13.9	2.6	-0.4	-0.1	0.4*	0.1
42	0.2	-0.1	-0.9	0.6	21.4*	-1.3	0.2	-0.1	0.3	0.1
43	-0.1	0.0	-1.6	0.6	-0.1	-1.2	-0.1	-0.2	0.1	0.2
44	-0.4	0.2	-15.3*	-6.5	-5.5	0.4	-0.1	0.0	-0.1	-0.1
45	0.1	0.7	4.4	0.9	-6.1	-6.8*	0.1	0.1	0.0	0.3
46	-1.3	0.4	-3.4	-4.8	-12.9	1.8	0.0	0.1	0.1	0.1
47	0.6	-0.6	-0.7	4.5	17.1	0.3	0.2	-0.2	0.2	0.0
48	-0.3	0.0	-12.4	-6.4	12.7	-0.9	-0.1	0.1	0.1	0.2
49	-1.4	2.0*	0.6	-3.1	-8.1	5.0	0.0	-0.2	0.2	0.2
50	0.0	0.3	-1.4	0.7	-17.8	1.7	0.0	0.0	-0.1	0.1
51	-0.8	-0.2	-7.6	-6.8	2.0	0.3	0.4	0.0	0.2	0.1
52	-0.3	0.2	-1.9	3.1	6.5	-2.8	0.1	0.2	-0.2	-0.1
53	-1.1	0.5	-4.4	0.8	2.5	-4.8	0.1	-0.2	-0.1	0.1
54	-1.7	0.9	-6.2	-0.5	-14.7	-2.7	0.1	-0.1	0.1	0.3
55	-0.5	0.0	1.3	0.8	11.5	7.4*	-0.2	-0.2	0.4	0.0
56	0.1	0.2	-0.6	-2.6	-0.1	-0.2	-0.2	-0.2	0.1	0.1
57	-0.8	0.7	1.0	-5.6	17.1	1.4	0.0	-0.1	0.1	0.0
58	-0.4	1.4	-2.0	-0.9	1.6	0.3	0.3	0.0	0.3	-0.1
59	-0.5	-0.2	1.0	4.1	8.2	-6.2	0.2	-0.1	0.0	-0.2
60	-0.1	0.8	2.7	0.9	-17.4	3.9	-0.2	0.0	0.0	-0.1
61	-0.3	0.8	8.4	-0.1	-14.1	5.8	-0.1	0.1	0.0	0.0
62	-1.0	1.5	1.2	0.5	-12.7	5.9	0.0	0.2	0.2	0.1
63	1.3	-1.1	-1.7	1.9	-2.7	-0.6	0.3	0.0	-0.2	-0.3
64	-0.7	0.6	-2.7	-4.2	-1.5	3.2	0.0	0.2	0.2	0.1
65	2.6**	-2.8**	25.1***	10.4*	0.7	-2.8	-0.1	0.1	-0.4	-0.5**

Appendix XVIII. Specific combining ability estimates with Tester B for grain yield and yield related traits across locations.

	SCA TESTER-B								
LINE	GY	AD	PH	EH	HC	ER	GLS	NLB	EA	PA
1	-0.5	0.4	0.4	-1.0	6.8	1.4	0.1	-0.1	-0.1	0.0
2	1.0	-0.5	1.0	-5.8	11.2	-3.4	-0.2	0.1	0.2	0.0
3	0.8	-0.8	-0.8	-1.5	2.8	-1.7	0.0	0.0	-0.1	-0.1
4	0.4	-0.3	0.3	-0.9	-12.5	-3.1	-0.1	-0.2	-0.2	-0.2
5	0.3	-0.1	-2.4	-1.1	14.9	-0.1	-0.1	0.1	0.0	0.2
6	-0.3	0.8	7.5	4.3	-10.1	1.6	0.0	-0.1	-0.2	-0.1
7	-0.1	0.3	-1.8	-0.3	10.7	0.6	0.4	0.0	0.2	0.2
8	-1.4	2.1*	-10.0	-6.5	-14.8	-0.3	0.3	-0.3*	0.2	0.3
9	-0.9	1.2	-1.0	-3.9	3.6	-2.4	0.4	-0.2	0.1	0.1
10	-1.7	0.8	-5.2	-2.2	-6.2	9.1**	0.1	0.2	0.3	0.1
11	-0.6	-0.4	-2.9	2.2	3.9	0.3	0.3	-0.2	0.3	0.0
12	0.9	0.9	4.4	3.0	-13.5	1.4	0.0	0.1	-0.2	-0.3
13	0.4	-0.2	0.2	-1.0	-9.4	-2.3	-0.2	0.1	-0.2	-0.1
14	0.3	-1.1	7.5	4.1	10.6	0.7	0.4	0.2	0.0	0.1
15	-0.1	0.0	1.6	5.0	12.7	-0.6	-0.2	0.1	0.1	0.1
16	-1.6	0.0	-3.6	-4.9	3.4	6.4	-0.1	-0.1	0.4	0.1
17	0.3	0.1	1.4	3.6	-5.9	-4.0	-0.2	-0.2	-0.2	0.0
18	-0.3	-1.4	-11.6	-5.0	-3.4	-0.8	-0.3	0.1	0.1	0.1
19	0.1	-0.1	4.5	-1.0	-11.2	-0.5	-0.3	0.0	-0.2	-0.1
20	0.5	0.0	-0.1	-5.5	1.7	-1.1	0.0	0.1	-0.1	0.0
21	0.8	0.7	1.0	2.8	-10.3	-2.2	-0.2	-0.1	-0.2	-0.4*
22	-0.5	-0.5	-2.2	-5.6	9.8	1.5	0.76**	0.1	0.2	0.1
23	-3.0**	2.1*	-25.4***	-9.4*	2.9	12.9***	0.3	-0.1	0.7***	0.6**
24	-1.5	1.5	-13.6*	-9.5*	-14.9	4.5	0.0	-0.1	0.2	0.2
25	-1.9*	0.6	-7.3	-1.2	5.6	0.8	0.0	0.2	0.2	0.1
26	0.5	-0.6	0.6	6.5	-13.8	-3.0	-0.5*	-0.1	-0.2	-0.2
27	0.7	-1.3	3.5	-0.1	1.5	-0.9	-0.6*	0.1	-0.1	-0.2
28	-1.5	1.7	-2.5	-2.3	-7.1	0.7	0.1	0.2	0.3	0.1
29	-2.0*	1.9*	-9.6	-7.2	14.3	5.0	0.3	0.1	0.6**	0.6**
30	-1.0	0.4	-3.9	0.1	4.5	-3.0	0.5	-0.3*	0.2	0.2

31	0.6	0.0	8.9	10.2*	-1.3	-2.2	0.5	-0.1	-0.1	0.0
32	0.9	-0.3	10.5	5.0	9.3	-5.7	-0.3	0.0	-0.3	-0.3
33	0.1	0.1	-1.0	-2.0	12.6	0.7	-0.4	0.2	0.1	0.0
34	0.0	-0.8	-4.8	-5.2	-3.7	3.3	0.0	-0.2	-0.1	-0.1
35	0.7	0.1	0.7	-1.3	7.9	-4.0	-0.4	0.1	-0.1	-0.2
36	1.91*	-0.7	2.4	2.9	7.5	0.6	-0.2	-0.2	0.1	-0.2
37	-0.4	-0.3	9.2	5.1	-5.7	-0.5	-0.2	0.1	-0.1	0.2
38	0.8	0.7	4.9	7.1	-11.6	4.2	0.1	-0.1	-0.2	-0.1
39	-0.1	-0.6	7.9	2.0	-1.3	-2.0	0.4	-0.1	-0.1	0.1
40	0.2	-0.6	1.5	4.0	-0.5	-1.7	-0.1	0.1	0.2	-0.2
41	0.2	0.3	12.8	4.3	-13.9	-2.6	0.4	0.1	-0.43*	-0.1
42	-0.2	0.1	0.9	-0.6	-21.4*	1.3	-0.2	0.1	-0.3	-0.1
43	0.1	0.0	1.6	-0.6	0.1	1.2	0.1	0.2	-0.1	-0.2
44	0.4	-0.2	15.3*	6.5	5.5	-0.4	0.1	0.0	0.1	0.1
45	-0.1	-0.7	-4.4	-0.9	6.1	6.7*	-0.1	-0.1	0.0	-0.3
46	1.3	-0.4	3.4	4.8	12.9	-1.8	0.0	-0.1	-0.1	-0.1
47	-0.6	0.6	0.7	-4.5	-17.1	-0.3	-0.2	0.2	-0.2	0.0
48	0.3	0.0	12.4	6.4	-12.7	0.8	0.1	-0.1	-0.1	-0.2
49	1.4	-2.0*	-0.6	3.1	8.1	-5.0	0.0	0.2	-0.2	-0.2
50	0.0	-0.3	1.4	-0.7	17.8	-1.7	0.0	0.0	0.1	-0.1
51	0.8	0.2	7.6	6.8	-2.0	-0.3	-0.4	0.0	-0.2	-0.1
52	0.3	-0.2	1.9	-3.1	-6.5	2.8	-0.1	-0.2	0.2	0.1
53	1.1	-0.5	4.4	-0.8	-2.5	4.8	-0.1	0.2	0.1	-0.1
54	1.7	-0.9	6.2	0.5	14.7	2.7	-0.1	0.1	-0.1	-0.3
55	0.5	0.0	-1.3	-0.8	-11.5	-7.4*	0.2	0.2	-0.4	0.0
56	-0.1	-0.2	0.6	2.6	0.1	0.2	0.2	0.2	-0.1	-0.1
57	0.8	-0.7	-1.0	5.6	-17.1	-1.4	0.0	0.1	-0.1	0.0
58	0.4	-1.4	2.0	0.9	-1.6	-0.3	-0.3	0.0	-0.3	0.1
59	0.6	0.2	-1.0	-4.1	-8.2	6.2	-0.2	0.1	0.0	0.2
60	0.1	-0.8	-2.7	-0.9	17.4	-3.9	0.2	0.0	0.0	0.1
61	0.3	-0.8	-8.4	0.1	14.1	-5.8	0.1	-0.1	0.0	0.0
62	1.0	-1.5	-1.2	-0.5	12.7	-6.0	0.0	-0.2	-0.2	-0.1
63	-1.3	1.1	1.7	-1.9	2.7	0.6	-0.3	0.0	0.2	0.3
64	0.7	-0.6	2.6	4.2	1.5	-3.2	0.0	-0.2	-0.2	-0.1
65	-2.6**	2.8**	-25.1***	-10.4*	-0.7	2.8	0.1	-0.1	0.4	0.48**

Appendix XIX: Similarity Report



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