EVALUATION OF WHEAT LINES IN SEMI- ARID AREAS FOR DROUGHT TOLERANCE UNDER RAINFED CONDITIONS.

By

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A thesis submitted to graduate school in Partial fulfilment of the requirements for the Degree of Master of Science in Crop Production of Egerton University.

EGERTON UNIVERSITY

OCTOBER, 2001.

APPROVAL PAGE

I declare that " EVALUATION OF WHEAT LINES IN SEMI ARID AREAS FOR DROUGHT TOLERANCE UNDER RAINFED CONDITIONS" is my own work and to the best of my knowledge the said work has not been presented in part or as whole for a degree in any other institution of learning. All sources I have used or quoted have been acknowledged by means of complete reference.

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This thesis has been written with our approval as university supervisors

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DEDICATION

This thesis is dedicated with deep love to

my Dad Samson Mwarey

and

Mum Sarah Koima Mwarey.

Acknowledgement

No amount of words can suffice to say thank you to all the people who helped me in one way or another. As I reflect back on what lies behind the success of this project there is undoubtedly a group of contributors who have made its completion not only possible but a reality. I acknowledge the necessary funding received from CIMMYT EU PROJECT, through Kenya Agricultural Research Institute. It has been a great pleasure to have worked for a wheat project that was guided with so much interest under the guidance of Dr. T. Payne.

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Evaluation of wheat lines in semi arid areas for drought tolerance under rainfed conditions

By Mwarey K. Mathew.

ABSTRACT

A study was conducted with the objective of screening for drought tolerance, testing the yield potential and stability of the introduced lines, comparing the lines with the check varieties recommended for the marginal environments and assessing G x E interaction of these introduced lines. In a yield trial eighteen introduced lines and two checks were evaluated at Katumani for two seasons, Elementaita and Lanet beef research station. Randomised complete block design (RCBD) was used and the plot size was 4 rows of 4 metres and the rows were spaced at 20 cm. 190 lines were also evaluated as a Semi Arid Wheat Screening Nursery (SAWSN). Nursery plot comprised of two one metre long rows, which were 20 cm apart. Grain yield, tillers per plant, spikelets per spike, plant height, number of days to maturity and number of days to heading, harvest index, kernel weight and above ground biomass were measured.

Stability analysis was also determined using regression methods. Correlation among variables was performed in specific environments and when environments were combined. Genotype by Location interaction effects were highly significant with spikelets per spike and harvest index showing significance at $P < 0.05$. Ear length showed a non significant G x E interaction. Plant height, above ground biomass, Kernel weight, spikelets per spike were highly correlated

with yield. (r = 0.565**, 0.795**, 0.727** and 0.704** respectively). Days to heading and days to physiological maturity showed a negative correlation with yield. The traits that were stable for most genotypes were tillers per plant, spikelets per spike and days to maturity, whereas plant height and above ground biomass were unstable.

Entry number 7, 8, 9, 14, 17 and 18 had broad adaptation. Entries number 7, 8, 9,11 and 18 had good performance among the introduced lines and even out yielded the check varieties. Genotypes varied in their stability. Entry number 10,11 and 15 showed better stability although their yields were low.

LIST OF ABBREVIATIONS

ASI	Anthesis to Silking interval
CIMMYT	International Maize and Wheat Improvement Centre
ICARDA	International Centre for Agricultural Research in Dry Areas
NDLRC	National Dry Land Research Centre
NPBRC	National Plant Breeding Research Centre
SAS	Statistical Analysis System
SAWSN	Semi Arid Wheat Screening Nursery
SAWYT	Semi Arid Wheat Yield Trial.
KARI	Kenya Agricultural Research Institute
G X E	Genotype by Environment Interaction.

LIST OF TECHNICAL TERMS

Drought Tolerance – ability of genotypes withstand water deficit and produce yield.

Drought avoidance - high water conservation and rapid extraction of soil water during drought.

Drought recovery - ability of crop plants to resume growth and give satisfactory yield after drought spell.

Drought escape – ability of plants to mature early and produce yield before drought sets in.

Biological stability – production of a constant yield by a genotype whatever the environmental condition.

Agronomic stability – yield varies in proportion to productivity of environments.

Genotype by Environment Interaction – Reaction of genotype to various environments.

Marginal areas – areas receiving less than 650 mm rainfall annually.

TABLE OF CONTENTS

APPROVAL PAGE ii
DEDICATION iii
ACKNOWLEDGEMENT iv
ABSTRACT vi
LIST OF ABBREVIATION viii
LIST OF TECHNICAL TERMS ix
TABLE OF CONTENTS x
LIST OF TABLES xiii

CHAPTER ONE 1

1.0 INTRODUCTION 1

1.1 WHEAT CLASSIFICATIONS AND CULTIVATION. 1

1.2 STATUS OF WHEAT IN KENYA 1

1.3 VARIETY DEVELOPMENT 5

1.4 OBJECTIVES 6

1.5 HYPOTHESES 7

1.6 JUSTIFICATION OF THE STUDY 7

CHAPTER TWO 8

2.0 LITERATURE REVIEW 8

2.1 CHARACTERISTICS OF MARGINAL AREAS OF KENYA 10

2.2. CONSTRAINTS TO WHEAT PRODUCTION. 11

2.3 VARIETAL SELECTION 13

2.4 INFLUENCE OF DROUGHT ON WHEAT PERFORMANCE 15

2.4.1 Effect of drought on wheat yields 17
2.4.2 Effects of drought on morphological traits 18
2.4.3 Effects of drought on yield components 20

2.5 SCREENING METHODS 23

2.6 SELECTION IN TARGET ENVIRONMENT 27

2.7 MULTI-LOCATIONAL TESTING 29

2.8. SITES FOR SELECTION. 31

CHAPTER THREE 33

MATERIALS AND METHODS 33

3.1 EXPERIMENTAL SITES. 33

3.2 TEST MATERIAL/LINES 34

3.3 FIELD LAYOUT AND EXPERIMENTAL DESIGN 36

3.3.1 Yield trial 43
3.4.2 Semi arid wheat screening nursery 38

3.4 DATA ANALYSIS 41

CHAPTER FOUR 43

RESULTS AND DISCUSSION 43

4.1 YIELD TRIAL 43

4.1.1 Tillers per plant 43
4.1.2 Spikelets per spike 49
4.1.3 Ear length 51
4.1.4 Plant height 53
4.1.5 The above ground plant biomass 57
4.1.6 Days to 50 % heading 63
4.1.7 Days to 50 % physiological maturity 64
4.1.8 Number of grains per head 67
4.1.9 Harvest index 68
4.1.10 One thousand kernel weight 72

4.2. GRAIN YIELD 76

4.3. CORRELATION ANALYSIS: 83

4.3.1 Relationship among yield components 83
4.3.2 Correlation of yield with yield components 87

4.4 GENOTYPE BY ENVIRONMENT (G X E) INTERACTION 99

4.5 STABILITY ANALYSIS 102

4.6 SEMI ARID WHEAT SCREENING NURSERY (SAWSN) 111

CHAPTER FIVE **122**

5.0 CONCLUSIONS AND RECOMMENDATION 122

5.1 Yield trial 122

5.2 Screening nursery (SAWSN) 125

REFFERENCES **127**

APPENDICES **137**

LIST OF TABLES

TABLE 1: PEDIGREE FOR ENTRIES TESTED IN A WHEAT YIELD TRIAL DURING THE GROWING SEASON OF 1998/1999.....39

TABLE 2: MEAN SQUARES VALUE FOR YIELD AND YIELD COMPONENTS OF 20 BREAD WHEAT GENOTYPES GROWN IN KATUMANI AND ELEMENTAITA IN 1998/1999. 47

TABLE 3: MEAN VALUES FOR YIELD AND YIELD COMPONENTS OF 20 WHEAT GENOTYPES GROWN IN KATUMANI , KENYA DURING (1998/1999).....48

TABLE 4:.MEAN VALUES FOR AGRONOMIC CHARACTERISTICS OF 20 GENOTYPES GROWN DURING THE SECOND SEASON IN KATUMANI, KENYA (1999) 54

TABLE 5: MEAN SEPARATION OF YIELD COMPONENTS OF 20 WHEAT GENOTYPES TESTED IN A YIELD TRIAL IN ELEMENTAITA, KENYA DURING THE GROWING SEASON OF 1999 59

TABLE 6: COMBINED ANALYSIS OF VARIANCE FOR YIELD AND YIELD COMPONENTS OF 20 BREAD WHEAT GENOTYPES GROWN IN THREE SITES IN KENYA DURING THE 1998/99 GROWING SEASON.....62

TABLE 7: COMBINED MEAN SEPARATION OF YIELD COMPONENTS OF 20 BREAD WHEAT GENOTYPES TESTED IN A YIELD TRIAL IN THREE LOCATIONS IN KENYA DURING THE 1998/1999 GROWING SEASON.....71

TABLE 8 : MEAN YIELDS OF TWENTY BREAD WHEAT GENOTYPES TESTED IN THREE ENVIRONMENTS DURING THE 1998/1999 GROWING SEASON IN KENYA.....81

TABLE 9: SEPARATION OF YIELDS AND YIELD COMPONENTS OF 20 BREAD WHEAT GENOTYPES BY LOCATION 82

TABLE 10: CORRELATION MATRIX OF YIELD AND YIELD COMPONENTS MEASURED DURING THE FIRST SEASON IN KATUMANI IN 1998/1999 GROWING SEASON. 92

TABLE 11: CORRELATION MATRIX OF YIELD AND YIELD COMPONENTS MEASURED DURING THE SECOND SEASON AT KATUMANI IN 1998/1999 93

TABLE 12: CORRELATION MATRIX OF YIELD AND YIELD COMPONENTS MEASURED IN ELEMENTAITA DURING THE 1999 GROWING SEASON. 94

TABLE 13. COMBINED CORRELATION MATRIX OF 20 GENOTYPES FOR 10 AGRONOMIC TRAITS MEASURED DURING THE 1998/1999 GROWING SEASON. 95

TABLE 14. RANKING OF GENOTYPES MEAN YIELD OF THE YIELD TRIAL IN THREE ENVIRONMENTS DURING THE 1998/1999 GROWING SEASON. 100

TABLE 15: THE SLOPE(B) OF THE AGRONOMIC TRAITS FROM THE LINEAR REGRESSION ANALYSIS AS INDICATORS OF STABILITY. 105

TABLE 16: RELATIVE YIELD (% OF MEAN SITE YIELD) OF 20 BREAD WHEAT ENTRIES AT THREE SITES IN KENYA. 109

TABLE 17. YIELD AND PLANT HEIGHT OF THE EIGHTEEN ENTRIES AND TWO CHECKS TESTED IN A YIELD TRIAL IN LANET DURING THE 1999 GROWING SEASON. 110

TABLE 18.1 ACTUAL YIELDS, YIELD AS % OF LOCAL (DUMA) CHECK AND RANKS OF THE HIGHEST YIELDING ENTRIES OF THE NURSERY TRIAL IN THREE ENVIRONMENTS. 114

TABLE 18.2. PLANT HEIGHT, HARVEST INDEX AND ASSOCIATED RANKS OF SELECTED ENTRIES IN THE SEGREGATING MATERIAL OF THE SEMI ARID WHEAT SCREENING NURSERY DURING THE 1998/99 GROWING SEASON IN KATUMANI 116

TABLE 18.3 YIELD COMPONENTS OF SELECTED ENTRIES OF THE SEGREGATING POPULATION OF THE SEMI ARID WHEAT SCREENING NURSERY 117

TABLE 18.4 YIELD COMPONENTS OF SELECTED ENTRIES OF THE SEGREGATING POPULATION OF THE SEMI ARID WHEAT SCREENING NURSERY MEASURED IN ELEMENTAITA DURING 1999 GROWING SEASON. 118

TABLE 18.5 CORRELATION MATRIX FOR YIELD AND YIELD COMPONENTS MEASURED IN THE SEMI ARID WHEAT SCREENING NURSERY DURING THE FIRST SEASON

(1998/99) IN KATUMANI. 119

TABLE 18.6 CORRELATION MATRIX FOR YIELD AND YIELD COMPONENTS MEASURED IN THE SEMI ARID WHEAT SCREENING NURSERY DURING THE SECOND SEASON (1999) IN KATUMANI 119

TABLE 18.7 CORRELATION MATRIX FOR YIELD AND YIELD COMPONENTS MEASURED IN THE SEMI ARID WHEAT SCREENING NURSERY DURING THE 1999 IN E ELEMENTAITA 120

TABLE 18.8 COMBINED CORRELATION MATRIX FOR YIELD AND YIELD COMPONENTS MEASURED IN THE SEMI ARID WHEAT SCREENING NURSERY DURING THE 1998/99 IN KATUMANI AND ELEMNTAITA 121

CHAPTER ONE

1.0 INTRODUCTION

1.1 WHEAT CLASSIFICATIONS AND CULTIVATION

Wheat cultivation is as old as ancient civilization of Babylon, Egypt, Greece and Rome. The exact area of origin or its complete ancestry is unknown. However, its cultivation is thought to have had its origin in the Fertile Crescent of the Middle East (Inglet, 1974). Wheat is grown across a wide range of environments around the world. It has the broadest adaptation of all cereal crop species (Curtis, 1988). In Kenya, wheat growing has been going on since its introduction by the European settlers in early 1900's.

Wheat (wild and cultivated) belongs to Genus *Triticum*, and can be classified into diploid, tetraploid or hexaploid depending on the number of chromosomes in their reproductive cells. Most of the world wheat is hexaploid, known botanically as *Triticum aestivum* (Bajaj, 1990) and accounts for 80% of wheat consumption in the world (FAO, 1996).

1.2 STATUS OF WHEAT IN KENYA

Wheat is an important grain crop in the world after rice providing nearly 20% of the total food requirements. It utilises about 30% of land under cereal cultivation and accounts for 27 % of world cereal production (Onazi *et al.*, 1988). In Kenya wheat is second cereal in importance, after maize (KARI, 1991) and is produced by both large and small- scale farmers with large-scale farms comprising

about 64% of total area under wheat (Kinyua *et al.*, 1989). It has mainly been grown in high potential areas that cover about 15% of the total area of Kenya (Kusewa and Guiragossian, 1991). The major growing districts are Uasin Gishu, Narok, Nakuru, Trans-Nzoia, Baringo and Laikipia in Rift Valley Province, Meru in Eastern Province and Nyandarua in Central Province (Kinyua *et al.*, 1989).

There are two major types of wheat, which are suitable for different agro-ecological zones in Kenya namely bread wheat and durum wheat. Bread wheat is grown specifically for bread making purposes while durum wheat is suitable for confectionery and pastry. Durum wheat is not widely grown in Kenya and almost all that is utilized is imported (Tanner *et al.*, 1996). Different zones in Kenya are classified into medium high and low potential areas. Traditionally wheat was produced in Kenya under large-scale system on medium and high potential land High potential areas receive rainfall sufficient in amount (over 1400 mm per year) and well distributed. Medium potential areas receive rainfall of about 700-1400mm per annum whereas low potential areas receive less than 650 mm per annum (Kusewa and Guiragossian 1991). In the low potential areas, wheat competes with different uses of the land under complex tenure arrangement such as communal grazing and wildlife (Hassan and Mwangi, 1992). In Kenya, areas receiving less than 650 mm of rainfall per annum are regarded as marginal for crop production and occupy over 80% of the country (Kusewa and Guragossian, 1991).

However, post independence institutional reforms have led to major structural changes in the country's wheat supply sector. The redistribution of

traditional wheat land to new owners has for instance affected wheat production. Prior to 1974, Kenya produced more wheat than its domestic demand. The surplus was exported to neighboring countries and Saudi Arabia. Since then, Kenya has imported wheat. Wheat growing areas declined by 23% between 1970-1980, because of land sub-division and distribution of large-scale farms, for resettlement purposes (Nyoro, 1995). Other land parcels that were transferred to a large number of small-scale farms have undergone changes in enterprise mix. Area under wheat gradually increased between the years 1980 and 1987 as wheat expanded to non-traditional wheat growing areas such as Narok, Trans Mara and Samburu. These areas are generally low in altitude and marginal for wheat production and yields obtained from these marginal areas are lower than those of traditional wheat growing areas. Since 1988, area under wheat has decreased because maize and dairy among other enterprises have competed with wheat in traditional wheat growing areas such as Trans-Nzoia and Nakuru (Nyoro, 1995). This is due to the fact that in addition to unfamiliarity with wheat farming by small-scale farmers, maize being the main stable food has been accorded higher priority over wheat. The former "million acre scheme" in Kinangop / Nyandarua is a good example of this major structural change in wheat production. This scheme used to account for 40% of the country's wheat supply in the seventies but now it accounts for only 2% after sub-division. Maize production and small-scale dairy farming have replaced wheat in the small farm production system in the area (Hassan and Mwangi, 1992).

Area under wheat and yield per unit area increased in early years because of expansion and improved technology. Currently acreage has declined due to land sub-division and resettlement and yields have stagnated at below 2 tons/ha due to diverse agro-ecological conditions and characteristics outside traditional wheat growing areas (Nyoro, 1995). Kenya has the potential to produce enough wheat for domestic consumption estimated at 700,000 tonnes but it only produces 300,000 tonnes thus it is not self sufficient (Rees *et al.,* 1997). This implies that Kenya import more than half of its domestic wheat requirements. With the growing challenges of meeting external debts, there is an urgent need to intensify research to improve wheat production so that self-sufficiency can be attained. The major constraints in wheat production include poor farm management practices, diseases, pests, low yielding varieties and use of non-adapted varieties (Kinyua, 1991; Rees *et al.,* 1997).

High rate of population growth, urbanization, shrinking land per unit holding and unfavorable policy environment has increased demand for wheat. As a result, wheat importation has grown at a faster rate than domestic production in the past decade. Wheat production has so far showed a slow growth rate of 0.9% per year while consumption spurred by population growth, increased urbanization (7% per year) and changing consumption habits has been increasing by 5.1 % a year (Kamidi, 1997).

The challenge facing the country is to aggressively step up local production and produce enough wheat to meet her consumer needs. This can be met by

reducing pre and post harvest losses through improved pest and disease resistance. Increasing yield per unit area and expansion of area of wheat production into non-traditional areas (Macharia *et al.*, 1996).

1.3 VARIETY DEVELOPMENT

The shift of wheat production into the non traditional marginal areas calls for development of high yielding drought tolerant germplasm and technologies that are both moisture and soil conserving since these environments are relatively fragile (CIMMYT, 1991). Ways should be sought to utilize this land to produce food for the increasing population. Increasing productivity in existing wheat growing areas and developing suitable technologies for potential expansion of wheat production into non-conventional areas is a viable option. These areas are characterized by unreliable and poorly distributed rainfall with high temperatures occurring frequently, factors that drastically reduce grain yield (Sinha, 1988; Nyachiro, 1991; Rees *et al.*, 1997). Wheat production under these conditions will require high levels of management using adapted varieties and new technology to achieve sustainable economic yields (Anonymous, 1993). There is need to develop varieties that can grow in drought prone areas since the rainfall is low and erratic while temperatures are normally too high to be tolerated by the presently developed varieties. The development of drought tolerant wheat cultivars can bring about increases in food production through improved production methods and expansion of the hectarage particularly in the arid and semi arid regions.

The National Plant Breeding Research Centre (NPBRC) Njoro has the mandate to co-ordinate research work on wheat in Kenya. It is from here that all wheat varieties are released for commercial production. Over 150 varieties have been introduced and released by NPBRC Njoro since 1920's although about 20 varieties today, are popular for commercial production. The rest have been replaced over time (Karanja and Pinto, 1994). The varieties are developed by the Centre either from own crosses or introductions from foreign research institutions like International Maize and Wheat Improvement Centre (CIMMYT).

1.4 OBJECTIVES

In an attempt to expand area under wheat production particularly into marginal areas previously considered unsuitable, this study was undertaken to evaluate wheat lines in various drought prone environments. The study evaluated the performance of lines in relation to Duma, a variety released for drought prone areas. The evaluation helped in selecting and advancing superior genotypes to the next stage of testing and hopefully, in the long run, to be released as recommended varieties for the low potential marginal environment.

The objectives of the study were to:

1. Screen one hundred and ninety (190) entries of advanced introduced lines for drought tolerance and possibly select those which can be used as new sources of adaptable varieties to drought in Kenyan wheat breeding program.
2. Asses the potential yield and stability performance of eighteen (18) selected elite lines over sites.

3. To test genotype by environment interaction of wheat lines grown over locations and seasons.
4. To compare the performance of lines with Duma and Ngamia varieties recommended for marginal environments.

1.5 HYPOTHESES

The hypotheses tested were that

1. Wheat varieties and introduced lines do not differ in drought tolerance
2. Among the elite lines none is superior in terms of yield potential (grain yield), stability to recommended varieties for marginal environments (areas).
3. Genotypes do not react differently to different environments.

1.6 JUSTIFICATION OF THE STUDY

These lines can be used in crosses for development of varieties that are better adapted to drought conditions. The high yielding drought tolerant varieties once developed will be grown profitably in marginal areas. This will boost domestic production and help maintain food security. In addition to saving the scarce foreign exchange presently spent on imports, they will also raise the income base and therefore improve the standard of living of those Kenyan's living in marginal environments. Imports between 1974 and 1991, for example, increased at an average rate of 13.1% per year. This led to the country spending a lot of foreign exchange (Kamidi, 1997).

CHAPTER TWO

2.0 LITERATURE REVIEW

One of the major objectives of Kenya development policy is to meet an ever-increasing demand for food stemming from rapidly expanding population and diminishing per capita income. Nearly all the nation's food requirement will need to be met from domestic production for the nation to be self-sufficient (Wangati, 1991). The agricultural sector must continue to generate foreign exchange earning to pay for oil, capital equipment and other imports and at the same time it must create new jobs for the rapidly growing labour force. In spite of gradual decline in growth rate from 3.3 % in 1993 to projected 2.6 % in 2013, the population of Kenya is expected to increase to 46.6 million by the year 2013 (KARI, 1993). To meet food demand by the year 2013 assuming a 1993 diet and a move to self sufficiency, wheat production must increase to 429 thousand metric tonnes (KARI, 1993). This is an increase of 120 % of the current production.

A significant problem for agriculture in the world is the major variation in crop yields from year to year due to disparity in environmental stresses such as drought, flooding, salinity, high and low temperatures (Janick, 1994). Constraints of physical environment (climate,water and soils) are important factors that determine agricultural production. This not only impact on crops that are presently being cultivated but are also significant barriers to the introduction of plants into

new areas. In addition, stressful environments are often characterized by the occurrence of more than one stress concurrently. For example salinity is often associated with drought and drought is often associated with high temperatures (Janick, 1994). Crop yields are dependent upon the genetic potential of varieties and the growing environment (Tanner and Mwangi, 1992). The wide range of agro-ecological diversities significantly affects wheat production often resulting in unstable agricultural outputs. National production of wheat increased from an average of 11,700 tonnes in 1921- 1930 to 21,900 tonnes in 1981 - 1990 with average yield rising from 0.65 ton/ha to 1.75 ton/ha in the same period (KARI, 1993). However, the current national average yield of about 2 ton/ha is still far below the research potential of 4 ton/ha (Nyoro, 1995). Wheat supply sector has undergone major structural changes, but the demand for wheat flour and wheat products continue to outgrow supply. Self-sufficiency in wheat dropped from 132% in 1961-65 to 60% in 1985-87 (Hassan and Mwangi, 1992).

The ever-widening gap between supply and demand continues to be bridged by imports. Wheat imports increased from about 380,200 metric tonnes in 1994 to approximately 390, 640 metric tonnes in 1996 (FAO, 1996). To meet the projected demand of wheat, production will need to be extended into more of the arid and semi arid or marginal areas of Kenya.

2.1 CHARACTERISTICS OF MARGINAL AREAS OF KENYA

The marginal areas of Kenya include the semi arid and part of arid Zones (Ecological zone IV) in which rainfall is sufficient in net amount to support rain fed agriculture (Kusewa and Guiragosian, 1991). These areas receive rainfall which is limited and irregular, but where good management of resource base will support cropping usually as part of mixed farming systems. These areas receive less than 650 mm of annual rainfall and cover over 80% of Kenya's land area. (Kusewa and Guiragossian, 1991). Low yields, are experienced due to frequent drought, disease, insect pest, low fertility and lack of improved and adapted varieties. The rainfall pattern in total amount, distribution and duration of rainy period are the main climatic factors limiting agricultural production in arid and semi arid areas. Farmers in these areas must therefore cope with existing variability of rainy seasons, short and highly unpredictable dry spells, soils with low infiltration capacity and thus greater water erosion hazard and finally high evapo-transpiration rate during the growing season. Most of the dry areas are found in the Coast, Eastern, North Eastern and Rift Valley provinces. Some of these areas have bimodal rainfall pattern within a year as experienced in Eastern province where the long rains usually begin in March and end in May while short rains begin in October and end in December (Kusewa and Guiragossian, 1991). High temperatures and low humidity characterize these areas. The availability of adequate soil moisture for crop growth depends not only on amount of rainfall received but also in the water holding capacity of soil and their depths. The great

majority of soils in arid and semi arid areas of Kenya are alfisols with a weak surface structure due to low levels of organic matter and high sand content. The sub-soil has low porosity and low water holding capacity. There are few pockets of vertisols sometimes referred to as black cotton soils (KARI, 1991).

2.2. CONSTRAINTS TO WHEAT PRODUCTION.

A survey undertaken in Nakuru, Narok and Uasin Gishu districts where more than 80% of Kenya`s wheat is produced (Hassan and Mwangi, 1992) show that large scale wheat farming is more productive than small holder wheat in both high and low potential zones by 25% and 50% respectively. (Hassan *et al.*, 1993). Wheat faces less competition for land in low potential areas and hence farmers are relatively more specialised and efficient in wheat production. In contrast wheat has to compete with high value enterprises such as maize farming and dairy production for high potential land resources. In high potential zones, Maize generates yield levels (1.4 t/ha) that are twice those of low potential lands (0.7 t/ha). This indicates that while maize does not compete with wheat in low potential land, it has a yield advantage over wheat in high potential areas. The biggest competition for wheat in high potential areas however, comes from dairy production that uses about 57 % of land resource compared to 27 % in low potential zones (Hassan and Mwangi, 1992). These results indicate that there is great potential for wheat production in the marginal areas of Kenya especially on large scale farms rather than in the high potential areas where high wheat yields are required to compete with dairy

farming and maize. Currently yield levels of recommended varieties for drought prone areas range from 540 to 2610 kg/ha (Tanner *et. al* , 1996). Therefore identifying varieties that can yield over 500kg/ha in these risky environments is acceptable.

Among the various abiotic and biotic constraints of rain fed crop production, drought is the most severe abiotic constraint on a global basis (Nyachiro, 1991; Saxena, 1995). EL Hafid *et al.* (1998a) noted that in the rain fed farming system of Mediterranean region of Northern Africa water scarcity is a major constraint limiting crop production and that drought may occur at any stage of wheat development. Annual drought patterns dictate the distribution of cultivated plant species. Response to drought among wheat cultivars is well documented (Blum, 1988; Entz and Fowler, 1990; EL Hafid, *et.al.*, 1998 a, b and c). Cultivars within species have been observed to differ in drought resistance (Nyachiro, 1991). Under stress different wheat varieties vary in their efficiency in partitioning photosynthates to organs and compensate for yield loss at different stages. EL Hafid *et al.* (1998 b), while working on six Durum wheat cultivars observed a differential response of cultivars in terms of the physiological attributes which are associated with early season drought resistance.

Plants subjected to drought stress experience reduced moisture supply to plant tissues. The plant cells then dehydrate leading to closure of stomata, loss of turgidity and reduced expansion rates of leaf blades. The end result is reduced dry weight accumulation (Saulescu *et al.*, 1995). The mechanism of drought resistance

in plants can be classified into drought escape or avoiders and drought tolerance. Drought avoiders saves water by absorbing sufficient amount to keep up with the extremely rapid water loss (Blum, 1996). Drought resistance conferring factors may be defined as those factors, which equip the plants with a better capacity to withstand desiccation than non-resistant ones. These factors may be physiological, biochemical and morphological. EL Hafid *et al.* (1998 b) identified drought induced changes in carbon dioxide exchange rate, water loss rate, net carbon dioxide uptake to water loss ratio, stomatal resistance, relative water content and osmotic adjustment as key control points in determining the drought resistance of a cultivar. Nearly all stages of plant growth from seedling to maturity are affected by drought. However, Entz and Fowler (1990) reported that the critical period for water stress in wheat occurs before anthesis.

2.3 VARIETAL SELECTION

The development of cultivars with improved adaptation to dry condition has been an objective of numerous breeding programs (Christiansen and Lewis, 1982; Osmanzai *et al.*, 1988; Ehdaie *et al.*, 1988; Nyachiro, 1991). It involves extensive selection and testing for yield performance over diverse environments using various biometrical approaches. Improved adaptation according to Hall *et al.* (1979) is manifested in high average yield in representative environment and low variability. These empirical methods have led to development of drought tolerant cultivars of many crops such as wheat, barley, rice, maize, sorghum and soya bean (Blum, 1988). This approach

requires intricate statistical and biometrical designs because inheritance of yield is complex as it is determined by a multitude of physiological, biological and metabolic plant processes. Secondly various environments in which genotypes are tested are largely undefined (Blum, 1988). Through a series of preliminary yield trials in Kajiado, Nyachiro, (1991) showed that wheat could be grown in areas so far least expected to support the crop. However the author observed that the environment in semi arid areas needed to be characterized. Expansion into new areas should follow research conducted by breeders and agronomists and must be based on sound knowledge of soil type characteristics and seasonal moisture and temperature regime related to specific crop since they have a lot of influence on crop performance.

The scenario in many developing countries is that traditional area for the crops are often diminishing (under pressure from settlement). Expanded acreage is needed (due to total population increase) and the crop acreage often moves out into new marginal land area previously considered unsuitable for crop growing. Irrigation, breeding and selection of adapted varieties are most appropriate technologies of utilizing marginal areas. Since water is normally scarce and large capital is required for establishment of an irrigation system, breeding and selection of drought tolerant wheat varieties in target environments is most appropriate (Nyachiro, 1991).

The biggest question, which then arises, is whether we should breed for general regional adaptation or specific adaptation for different regions. However,

for a country like Kenya that has limited research resources, it is recommended that generally adapted varieties initially be identified as determined from yield performance. Additionally, use of germplasm with wide adaptation from international programmes, such as International Maize and Wheat Improvement Centre (CIMMYT) and International Centre for Agricultural Research in Dry Areas (ICARDA) is encouraged. Introductions are accessions (varieties or lines) which are imported into the country from other countries or from international centers such as CIMMYT. Once in the country they are subjected to seed pathogen detection tests before being released to national research station or other institutions. The station will plant these varieties or lines in open quarantine, evaluate and culture the grains and examine for any foreign diseases. Further evaluations are then carried out as desired. The current CIMMYT breeding methodology is based on the principles of increasing yield potential while simultaneously incorporating biotic and abiotic stress tolerance (Rajaram and Ginkel, 1996).

2.4 DROUGHT INFLUENCE ON WHEAT PERFORMANCE

In physical terms the problem of drought is quite simple to describe, define and quantify. The soil component of drought can be defined as the balance of moisture in the soil from the amount of rainfall received minus the amount lost through surface run off and deep drainage (contributing to ground water). The amount of plant available water in the soil profile would be between the limits of permanent wilting point and the field capacity, which is

specific to different soil types. For example it would be less available in a sandy soil compared to clay soils such as the black cotton soils. On the soil moisture, when we overlay the climatic evaporative demand and the transpiration demand of the crop, we get a good quantitative estimate of the magnitude of drought the crop experience over the crop-growing season. Drought is a multidimensional stress affecting plants at various levels of their organizations. The effect of and plant response to drought at the whole plant and crop level is complex because it reflects the integration of stress effects and response at all underlying levels of organization over time. Crop response to drought stress are mediated by processes of response to water deficit and associated strains at various levels of plant organization The complex part is to define the response or adaptation of plants to drought. Also the mechanism plants use for efficient extraction and use of the available soil moisture not only to survive but also for high crop growth and productivity, culminating in higher and stable yields. This means efficient water extraction mechanism, efficient regulation of the use of water extracted for maximum dry matter production and partitioning of this dry matter into grain yield. Plants manifest their responses to events of drought occurring during their development at sub cellular level, tissue level, plant level, crop and community level in production system (Saxena, 1995). Integrated effects of these events over time determine the productivity and the final economic yield. Therefore, seeds planted in dry soil with sub-optimal soil moisture content lead to uneven germination and emergence resulting in sub-

optimal than the recommended plant density necessary for obtaining high yields. Seedling mortality in a drying seedbed is a common problem in drought prone areas (Johnson and Asay, 1993). The problem is aggravated by excessively high soil temperature during seedling emergence and establishment (Peacock *et al.*, 1990).

2.4.1 EFFECT OF DROUGHT ON WHEAT YIELDS

In semi arid tropics and countries with semi arid to dry climates yield loss due to drought range from 30-60% depending on severity and type of drought, sometimes total crop failure occur (Saxena, 1995). The difference in yield levels among developing countries particularly in East, Central and Southern Africa is linked to variation in moisture availability due to difference in agro-ecological conditions and frequent droughts. In Kenya for example, drought is frequent and widespread and over 80% of the country experience drought (Kinyua *et al.*, 1994). Developing countries wheat yield vary from 2.6 ton/ha in irrigated areas to 0.6 ton/ha in very dry areas receiving less than 300mm of rainfall (CIMMYT, 1989). Average wheat yields have risen rapidly in environments where moisture is plentiful but in dry land areas, yield increases have been more modest. The reduction in grain yield of barley when moisture stress occurs at flowering and dough stage is more drastic than when it occurs at internode elongation (Craufurd *et al.*, 1993). Simane *et al.* (1993) reported that water stress during reproductive stages of wheat (from anthesis to maturity) resulted in wheat grain yield reduction of 88%. Of this percentage

58% reduction was observed during anthesis and 30% yield loss at grain filling. Byrne *et al.* (1995) observed that in maize, drought during the plant reproductive stage causes an appreciable delay in silking while anthesis is not delayed to such an extent. The result is an increase in anthesis to silking interval (ASI), which is an important cause for maize yield failure under drought stress. Countries where most wheat is grown under well watered conditions (irrigation and/or moderate to high rainfall) experienced sustained growth rate in yield of 4.4 % yearly from 1961-1965 to 1984-1986. This was more than double the rate of increase (2.1% yearly) in countries where significant areas of wheat are grown under drought stress (CIMMYT, 1989). This variation reflects the limiting effect of drought on yields in these risky environments.

2.4.2 EFFECTS OF DROUGHT ON MORPHOLOGICAL TRAITS

Studies evaluating drought resistance in wheat has shown that drought tolerant and drought susceptible genotypes differed significantly in their photosynthesis (EL Hafid *et al.,* 1998 b). Several characteristics have been considered important in adaptation to stress. For example osmotic adjustments is a mechanism that alleviates some of the detrimental effects of water stress by promoting both avoidance and tolerance (Blum, 1989).

Morphological traits associated with drought tolerance include maintenance of relative water content and chlorophyll loss under moisture

conditions (Al Hakimi *et al.*, 1998). Instantaneous leaf water use efficiency, defined as the ratio of leaf photosynthesis to transpiration measured simultaneously, has also received considerable scrutiny with respect to its postulated adaptive significance to plants growing in arid and semi arid climates (EL Hafid *et al.*, 1998 c). Efficiency of water use, the improvement of economic returns for the investment of water, is an ecologically important factor influencing the adaptation of crop species to water limited environment.

Resistance of photosynthetic apparatus to dehydration helps plants to survive under drought by maintaining photosynthetic capacity of the leaves thus allowing rapid recovery of the plant after rehydration. Drought decreases leaf water osmotic and pressure potential. EL Hafid *et al.* (1998 b) observed that the drought resistant cultivars had higher leaf water potential and relative water content than susceptible cultivars under water stress. When water stress was intense (i.e. leaf water potential below -2.0 mpa), some varieties had more negative osmotic potential at a given leaf, relative water content, indicating variation on osmoregulation. On average genotypes with high osmoregulation produced higher yields under varying soil water conditions.

Osmotic adjustment, water absorption and transpiration (Al Hakimi, *et al.*, 1998) influence relative water content. Exposure of wheat plants to water stress regimes reduces the rate of water loss and increases stomatal resistance. Drought resistant cultivars were observed to retain more water in the leaf tissue at a given water or osmotic potential under severe and to a lesser extend

under medium stress conditions compared to the drought susceptible cultivars (EL Hafid *et al.*, 1998 c). Drought tolerant genotypes exhibit a smaller stomatal resistance than susceptible genotypes under severe stress. The relative importance of stomatal and non stomatal effects of water stress in carbon dioxide fixation varies with magnitude of the stress and therefore an early decrease in photosynthesis under drought result from increased stomatal resistance.

2.4.3 EFFECTS OF DROUGHT ON YIELD COMPONENTS.

Water stress influences the yield components in different ways. Yield components include number of spikes per metre square, number of spikelets per spike, number of kernels per spike, kernel weight, tillers per plant and plant height. Craufurd *et al.* (1993) observed that the number of spikes per plant was not affected by stress treatment and water stress during heading had a significant effect in number of spikelets per spike and number of kernels per spike.

When water stress occurs either at the late vegetative phase or during the late inter-node elongation, development of wheat spike is impaired. Death of florets occurs at the terminal and basal ends of the spike due to male sterility caused by water stress. Drought at inter-node elongation, normally produces shorter plants with profuse tillering as observed by Kore and Ayiecho, (1996). EL Hafid *et al.* (1998 a), noted that the differential response of six wheat cultivars to drought was mainly, due to differences in number of kernels

produced. Jamieson *et al.* (1995) also reported that as drought stress increased mean kernel mass was reduced. The authors further observed that the yield responses were mostly associated with grain number in wheat and barley. Giunt et al. (1993) reported that severe water stress from seedling to maturity stage reduced all yield components particularly number of fertile ears per unit area by 60 % and grain number per ear by 48%. The water stress also caused early heading and maturity. The authors observed that better drought tolerance was associated with early heading, increased kernels per spike and rapid grain filling.

Leaf area development is sensitive to moisture stress. High yields under early season drought have been attributed to high leaf area index under stress and upon recovery to high tiller survival rate (EL Hafid *et al.*, 1998 a). High leaf and tiller numbers and faster leaf area development early in the season result in greater biomass production and greater early season ground cover in low rainfall environments. When water stress develops gradually in the plant the first change is most likely a slowing of shoot and leaf growth. Although these responses tend to enhance survival by conserving water they can be detrimental to productivity upon relief of water deficits because of resulting impact on the assimilation capacity of the plant (Ludlow and Muchow, 1990). Maintaining leaf area on the other hand contributes to yield but can be a potential threat to survival in a stressed environment.

Tillers play a central role in the recovery from early season drought. Genotypes which produces a large number of tillers and thus accumulating a large biomass, might deplete soil moisture earlier than genotypes with less prolific tillering (Schonfield *et al.*, 1988). When drought stress does not result in total plant death, the final crop consists of tillers, which were either subjected to drought stress or appeared soon after recovery. EL Hafid *et al.* (1998 a) noted that the duration of water stress was positively associated with proportion of tillers that appear after rewatering. The authors further observed that total dry matter production reduce less that grain yield. As water stress duration increased, grain number was reduced, while kernel weights remained relatively insensitive to water stress treatment considered. The number of Kernels produced per unit area has been reported to be the most important components determining wheat grain yield under pre-anthesis stress (Entz and Fowler, 1990).

Harvest index (H.I) provides an estimate of the conversion efficiency of dry matter to grain yield. While H. I. of same cultivars grown under optimal conditions approached and sometimes exceeds 0.4, it was generally much less under drought conditions with the same cultivars (EL Hafid *et al.*, 1998 a). Simane *et al.* (1996) observed that harvest index ranged from 0.2 to 0.5 among the varieties pooled over moisture treatment. The lowest harvest index was recorded by the drought susceptible variety and the highest was recorded by the drought resistant cultivars. The balance between dry matter produced before and after anthesis and the amount of remobilized pre-anthesis assimilate

determines Harvest index. Strong correlation between post anthesis water use and harvest index indicate that grain yield is highly dependent on biomass accumulation after anthesis (Simane *et al.*, 1996). Therefore, H. I of rain fed wheat crop is well below the potential and perhaps maximum grain yield is not achieved. Siddique *et al.* (1990) reported improved mechanism of partition between straw and grain (improved H.I) as the main causes of increased grain yield under a semi-arid Mediterranean type environment. From the above observation it can noted that the differential response of cultivars to drought have been attributed to difference in ability to maximize kernel production, maintain green leaf area under water stress and have high tiller survival rate.

2.5 SCREENING METHODS

The methods used for screening drought resistant materials can be grouped into either direct method that involves imposition of moisture stress on potted plants and field screening or indirect method, which includes seed germination in concentrated sugar solutions, root growth studies, hot air treatment, chlorophyll stability index and conduction tests. Due to high complexity of drought resistance owing to numerous interactions of both the environment and plant factors, screening plants for drought resistance directly in the field is perhaps the most accurate method (Pfeiffer, 1988). One of the most important objectives of screening nurseries is to provide wheat breeders with genetically variable germplasm. Screening nurseries also encourage germplasm exchange among wheat breeders and is a step in the right direction in development of tolerant germplasm

to major environmental stresses such as drought, salinity, diseases and high temperatures. Normally, screening nurseries are distributed to co-operators (scientists) in wheat growing areas. The entries are selected as having the best performance at several locations. Performance traits evaluated are adaptation, disease resistance, drought tolerance and potential grain yield. The semi arid wheat screening nursery (SAWSN) is a collection of lines and cultivars varying in level of tolerance to semi arid environments selected by scientist either from other foreign countries and CIMMYT or locally selected by Kenyan scientist particularly in Kenya agricultural Research Institute (KARI) Njoro. The entries selected are then screened in semi arid environments.

Breeding materials have to be exposed to the environment stress in order to identify genotypes that are better adapted. The complexity of the process affected by physical stress and the variability of the incidence of the stresses is such that it is almost impossible to fully mimic the stress environment and their effects on physiological processes by using controlled environment and /or laboratory tests (Acevedo, 1991). Therefore, the following conclusions can be drawn: -

(a) The effective selection procedure from a breeding standpoint has to be essentially based on field grown plants.

(b). The breeding material has to be exposed to drought stress at various stages of development.

(c). The final proof of stress tolerance is obtained on the target environment.

There are two approaches that have been used in selection for drought tolerance namely empirical and analytical approaches. In empirical approach, improvement of wheat yield is directly approached by breeding for yield while in analytical approach, a better understanding of the mechanism contributing to yield in dry environment are done considering that in these conditions indirect selection for specific trait might improve progress. The empirical approach uses the pedigree method, bulk method and single seed descent (SSD) while the analytical method uses indirect selection for yield where traits of interest are selected due to their association with yield. Of all these methods none is significantly more efficient in selecting for dry areas (Al Hakimi *et al.*, 1998). The two main steps in analytical approach as described by Clark *et al.*, (1992) are: -

1. Screening and selection of potential parents carrying the desired traits for incorporations of these Morpho-physiological traits into new cultivars.
2. Selecting in the segregating population for the Morphophysiological traits rather than selection for yield.

The effectiveness of incorporating the desired morphophysiological trait depends upon its heritability (Clark, 1992). Al Hakimi *et al.* (1998) indicated that the use of related species in combination with modified bulk breeding method appears to be promising for increasing durum wheat yield in drought prone environments and yield stability across contrasting environment.

Performance of wheat depends on the specific genotype, the environment in which they are grown and the interaction between genotype and environment (Agmas *et al.*, 1995). In an environment with variable rainfall patterns both yield potential and yield stability are equally important, therefore a synthetic breeding approach should be used with simultaneous selection in low yielding and high yielding environment to combine yield potential and drought resistance (Simane *et al.*, 1996). However, Boyer (1996) observed that improvement of yield under water limited conditions need not sacrifice yield under favorable conditions. Grain yield and its components have been used as major selection criteria for improved adaptation to stress environment (Blum, 1992). The use of yield components as selection criteria necessitates the determination of relationship among components and evaluation of the contribution of various component characters towards the ultimate crop yield (Kinyua and Kirigwi, 1994). The authors found out that those yield components, which were highly correlated with yield and could be used as selection criteria, were unstable over years and locations. They argued that it would therefore be risky to use unstable parameters during selection as the environment has a significant effect on them. The regression coefficient estimates of grain yield of genotypes tested were not significantly different from unit regression indicating that end observation (yield) was stable. Total drought resistance of a plant genotype cannot be defined physiologically and simple test of tissues for stress tolerance has not been developed adequately.

Therefore, conducting experiments at the actual stress locations and testing for grain yield and stability under these environments remain a major selection criteria for stress tolerance in many breeding programmes (Bruckner and Frohberg, 1987; Kinyua *et al.*, 1994).

Genotypes by environment interaction, makes the task of identifying an ideal variety that combines high yield and stability of performance across diverse growing environments difficult. Yield stability is complex because it involves genetic, physiological and phenological parameters. Heinrich, e*t al.* (1983) grouped mechanism of yield stability into four categories viz: genetic heterogeneity, yield component compensation, stress tolerance and capacity to recover from stress. Knowledge of varietal adaptation and stability over years and locations is important in order to select broadly adapted and stable varieties. Varieties need to be compared based on their behaviour in target range of production areas.

Since yield should be one of the most important drought tolerance plant attributes in marginal areas, it is a good index for screening crops for drought resistance under field conditions. In developing countries like Kenya one or few of the methods listed above could be used in any breeding program.

2.6 SELECTION IN TARGET ENVIRONMENT

The importance of yield under stress must combine a high yield potential with specific plant factors, which would buffer yield against a severe reduction under stress. Plants that perform well in dry areas must integrate

many characteristics that contribute to efficient use of moisture. Stand establishment and successful early tiller production have been shown to contribute to high yields under drought conditions (Blum *et al.*, 1990). The traits of high tillering capacity per plant and high plasticity of tiller number per plant (i.e. low variance of tiller number per unit area) can be used for selecting consistently high yielding lines in low rainfall areas (EL Hafid *et al.*, 1998 a). On the other hand potentially lower yielding genotypes occasionally have been found to perform well under drought stress conditions (Blum, 1988) The author further reported that physiological selection criteria must supplement yield. The utility of a particular characteristic as selection criteria in breeding program will depend upon the ease and cost of screening as well as upon the heritability. Beyond morphophysiological traits root characteristics and traits related to osmoregulation are frequently considered (Clark, 1988). Selection for morphophysiological traits related to moisture stress such as root volume and relative water content is possible (Al Hakimi *et al.*, 1998). However, using root growth as selection criteria is labour intensive and only relatively low numbers of genotypes can be screened (Clark, 1988).

Attempts to select for osmoregulating cell lines as means of improving drought (and salinity) resistance have been done (Jones *et al.*, 1988; Blum, 1988) but difficulty remain in recovering durable resistance in plantlet and plants. In addition the direct measurement of osmoregulation in large breeding population is practically impossible, selection based on canopy temperature has

been applied successfully for selection of wheat (Balota *et al.*, 1993). The measurement of gas exchange in various genotypes subjected to the same level of water stress deficit is slow and impractical in selection work and also requires expensive instrumentation that is not readily available. Harvest index (ratio of grain weight to total above ground biomass) is affected by size of the reproductive sinks and by the rate and duration of assimilation partitioning to the sink. Large stem reserves and a greater capacity for its remobilization would therefore support harvest index under drought stress. Selection for the capacity of grain filling by stem reserve mobilization under a post anthesis drought stress is difficult. It is nearly impossible to apply the proper selection pressure by affecting the same level of water stress during grain filling over a phenologically variable germplasm.

So far quite a number of characters have been associated with drought tolerance and water use efficiency. However the empirical approach of using grain yield under stress has given excellent results in breeding program for drought tolerance (Kohli *et al.*, 1991).

2.7 MULTI-LOCATIONAL TESTING

The seasonal short fall in rainfall in dry areas is exacerbated by its large variability both between and within years. Untimely rainfall makes it difficult to reliably impose and regulate irrigation treatment and unless there is very little rainfall, experiments must be repeated over several sites and/ or seasons to obtain sufficient data for the results to be meaningful (Jamieson *et al.*, 1995). In the last

20 years most major wheat-breeding programme in the world have adopted multi-locational testing in contrasting environment as an integral part of their breeding philosophy (Rajaram and Ginkel, 1996). Multi-locational testing is a strategy widely employed in plant breeding. It is routinely used in most national and regional programmes and is utilized on an extensive scale by international plant improvement centers (Smith, 1988). It has much merit in variety development programs since it is of special interest to breeders in semi arid zones because it utilizes genotype performance in natural stress environment. It constitutes a system of trials that are generally replicated over years as well as locations with the objective of predicting performance of breeder's lines and new varieties and their adaptation in relation to standard cultivar checks (KARI, 1993). Apart from hybridization, introduced material could also be used for crossing and/or evaluated in various locations and released when proved to be superior in abiotic and agronomic characters (KARI, 1995). The current CIMMYT breeding methodology is based on principle of increasing yield potential while simultaneously incorporating biotic and abiotic stress tolerance (Rajaram and Ginkel, 1996). At ICARDA, multi-locational screening of early generation and yield testing of advanced material in target environments has provided improved germplasm, combing high yield potential and consistent performance both in research site and in farmers field (Ketata, 1988). Pfeiffer (1988) indicated that genetic variance is usually high under favourable condition and the genetic advance is greater under drought stress. Hence selection of germplasm for drought stressed condition can be

done in both optimum water and reduced water situations. This is supported by Ritchie *et al.* (1990) who reports that at present the best and ultimate indicator of drought resistance used in wheat breeding programme is grain yield measured under well watered and water stressed conditions. Germplasm having stress tolerance in high yielding background can be exploited in variable on-farm conditions as in the case in many agriculturally stressed environments, where input responsiveness can occur in the better years (Rajaram and Ginkel, 1996).

Heritability of yield is reduced under stress. Selection for yield must therefore be performed in an environment that corresponds to the drought condition of target environment. Kore and Ayiecho (1996) report that certain triticale genotype can give high yields in the marginal areas of Kenya especially if selection of such genotypes is done in target areas. To overcome the low efficiency of such selection programme, selection can be done by growing large population and performing repeated testing over years and location to secure results (Gauch and Zobel, 1996). This will also increase the chance of including markedly superior genotypes. In order to make cultivars recommendation for either wide or specific adaptation stability analysis of yield data across environments and years is useful in a breeding program (Debelo *et al.*, 1996).

2.8. SITES FOR SELECTION.

In water limited production zones, the choice of site for screening needs some consideration. Evaluation of promising lines in several environments representing a range of relevant drought situation is imperative. Within the target

zone, there is access to a number of potential selection sites differing in degree of stress ranging from severe stress to non-stress condition (Smith, 1988). A site characterised by severe stress is prone to crop failure, which result in a loss of time and effort. In addition, it is difficult to detect inter genotypic difference for production traits when plants are severely stressed. Therefore the strategy is to use sites of moderate stress for initial selection and conduct progeny test under both stress and non-stress conditions.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 EXPERIMENTAL SITES.

This study was carried out in two sites. Elementaita is situated in Nakuru district whereas Katumani is situated in Machakos district. The sites where the trials were conducted are Kenya Agricultural Research Institute (KARI), National Dry-land Research Centre (NDLRC) Katumani for two seasons and at Elementaita for one season. These locations differed in altitude and climatic patterns particularly in rainfall and temperatures. Katumani is located in Eastern Kenya and lies at 1596 metres above sea level. It is at 1^0 31''S latitude and 37^0 14'' E longitude and has an average rainfall of 717 mm per year. It experiences a mean minimum temperature of 13.9 ^{0} C and a mean maximum temperature of 24.7^0 C. The temperature range was 20- 26^0 C during the time the study was carried out. The site lies in an agriculturally low potential dry land area classified as agro-ecological zone upper midlands four (UM4). The Katumani soils are acrisols undifferentiated with acronosols. They are shallow soils of fairly low yield potential and low fertility. They are excessive to well drained sandy loam to clay with moderate to heavy texture (Jaetzold and Schmidt, 1983). Long rains occur in March to May whereas short rains occur in October to December. In this study the long rains and short rains were 265 mm and 245 mm respectively during the growing seasons.

Water loss through evaporation in this environment is up to 1800 mm with a water deficit of 1048 mm per year.

Elementaita lies in altitude 1849 metres above sea level within agro-ecological zone upper midlands four (UM4), which has low agricultural potential. The site receives an average annual rainfall of 696 mm with mean minimum temperature of 10^0 C and mean maximum temperature of 26.4^0 C. The temperature range was $26\text{-}28^0$ C. The soils are moderately well drained, moderately deep, reddish brown to red, firm clay loam with humic topsoil (Jaetzold and Schmidt, 1983). The moisture availability is low as the annual average precipitation is 40- 50% of potential evaporation. The 60 % rainfall reliability per month in Elementaita has not exceeded 70 mm in the last 39 years. Evaporation in the last three decades has ranged from 135 mm to 179 mm per month (Jaetzold and Schmidt, 1983). These conditions of very low rainfall and reliability coupled with high evaporations are characteristics of most marginal environments. This is in addition to poor soil conditions particlarly the sandy soils commonly found in this area and have poor water holding capacities.The above soil and climatic conditions are representative of Kenya's semi-arid conditions

The test material and entries are described below:

3.2 TEST MATERIAL/LINES

This study utilized test materials obtained from Kenya Agricultural Research Institute (KARI) National Plant Breeding Research Centre (NPBRC)

Njoro. The test material comprised one hundred and ninety bread wheat lines as entries of a screening nursery and eighteen selected elite lines as entries of a yield trial. The entries for a screening nursery were selections from introductions from CIMMYT Semi-Arid Wheat Screening Nursery (15th and 16th SAWSN). Some lines from wheat performance yield trial, national performance trial, national variety trial and commercial variety trials were also incorporated into the screening nursery. The entries for yield trial were selections from Introductions from CIMMYT'S 6th Semi-Arid Wheat Yield Trial (6th SAWYT). In this trial, Duma and Ngamia were used as checks.

DUMA- This is a variety that was released in 1993 for marginal wheat growing areas of Kenya. It has an average yield of 540 to 2610 kg /ha and does well in altitude below 1800 m above sea level. It is an early maturing variety with good resistance to stem and brown rust and also to lodging but poor resistance to yellow rust.

NGAMIA- This is a commercial variety released in 1993 for the drought stressed marginal environment. It has clubby heads and is resistant to stem and leaf rust. It matures early yielding an average of 560 to 2520 kg /ha and does well in altitude below 1800 m above sea level.

The eighteen lines used in the yield trial were selections from the 6th SAWYT numbered; 2, 6, 7, 8, 13, 14, 16, 18, 19, 20 24, 28, 30, 32, 33, 40, 49, 50. The whole trial had initially been screened in Njoro and the above selections showed good tolerance to major diseases such as stem and brown rusts as well as

yellow rust and indicated a good yield potential. The entry numbers and the parentage of the yield trial are presented in Table 1.

3.4 FIELD LAYOUT AND EXPERIMENTAL DESIGN

3.4.1 YIELD TRIAL

Field experiments were conducted in Katumani during the short rainy season of October 1998 to February 1999 and also during the long rains season of March 1999 to August 1999. In Elementaita, experiments were conducted once during the growing season of March 1999 to August 1999. Each location in a given year was considered as an individual environment such that these lines were tested in three different environments. In the three experiments the field design was a randomised complete block design (RCBD) with three replicates. Plot size was 4 rows of 4 metres long with inter row spacing of 20cm and seeds were hand drilled along the rows. Seeding rates of 100 kg per hectare was used and DAP fertiliser, was applied at the rate of 130 kg per hectare. Agronomic practices such as weed control, pest and diseases control were carried out uniformly in all experimental sites, using the recommended management practices (Arama *et al.*, 1997). At maturity the whole plot was harvested.

Data were taken in each plot for the following traits: -

1. Heading date - This was the time when the head had completely emerged from the flag leaf. The date recorded was when 50% of the plants in a plot had headed.

2. Maturity time- this was the time when the vegetative plant parts had dried up (loss of chlorophyll) through normal physiological process and the grain reaching hard dough stage. The crop in each plot was considered mature around the date when 50% of the plants within each plot showed the signs of maturity.
3. Plant height (cm)- This was the height of the plant from ground level to the tip of the longest tiller. Plant heights were measured at maturity on three plants within the plot at random, and then averaged.
4. Number of tillers per plant - This was the number of head bearing tillers, counted, on ten plants from within each plot chosen at random and averaged. This was counted after the plants had headed.
5. Number of spikelets per head –At maturity the average number of spikelets was obtained. This was the average number of spikelets on ten heads of the primary tiller chosen at random from each plot.
6. Number of grains per head – Ten heads were taken randomly from each plot after the plants had matured and threshed together. The grains were then counted and averaged.
7. Yield per hectare (kg) - The weight of the harvested grain from each plot was obtained after threshing and cleaning. From the average figure, yield per hectare (kg) was calculated.
8. 1000 kernel weight (g) - One thousand grains were counted from each plot and their weights taken.

9. Harvest index - Above ground biomass was obtained by getting the weight of dry whole plants excluding the roots in a plot. The grains were threshed and grain weight per plot determined. The ratio of grain weights to the above ground biomass at harvest became the harvest index (H.I).

3.4.2 SEMI ARID WHEAT SCREENING NURSERY

A total of one hundred and ninety (190) entries comprising selections from 15th and 16th semi arid wheat screening nursery, locally developed entries and commonly used commercial varieties were planted at Katumani for two seasons and at Elementaita. The first planting in Katumani was carried out during the short rainy season of October 1998 to March 1999 while the second planting was done in the long rains of March 1999 to August 1999. In Elementaita trials were carried out in April 1999 to August 1999. Since it was an observation trial, each entry was planted in plots of 2 rows of 1 m long and spaced at 20 cm. The tolerant cultivar Duma was planted as a check after every 20 entries in all the trials. Proper land preparation was carried out in all the sites to ensure that weed infestation was kept as low as possible.

Table 1: Pedigree for entries tested in a wheat yield trial during the growing season of 1998/1999.

ENTRY No	CROSS / PEDIGREE / ORIGIN	SOURCE 6TH SAWYT NO
1	PAVON F 76 CM8399 - D4M - 3Y - 1M –1Y- 1M – OY - OMEX	2
2	DHARWAR DRY -OIND	6
3	W3918A / JUP CM40096 – 8M - 7T- OM	7
4	PASTOR CM85295 – 0101TOPY - 2M – OY –OM - 1Y- OM - OSY	8
5	IL – 75 – 2264 / 4 / CAR / / KAL / BB / 3 / NAC / 5 / GAA CM93935 – G - OM - OY – OH - 3Y - 08 - OSY	13
6	BAU / / PRL / VEE # 6 CM94708 – 3E – OE – OY - 1C - 6C – OC – OC - OSY	14
7	BJY / COC / / PRL / BOW CM95439 – 63Y – OH – OSY – 5M – ORES - OSY	16
8	CHIL / BUC CM95950 – 54Y – OM – OY – 5M – ORES	18
9	URES / JUN / / KAUZ CM96818 – I – OY – OM – O8 - 2Y - 1Y – OM - OSY	19
10	DUCULA / / VEE / MYNA CM103443 – 26 M- O30Y- O20Y- O10M- 3Y- O10Y- OM-OSY	20
11	MJI / GLEN / / TRT / 3 / BAU CM104780 – 4E – OY – OC – 3C – OC - OSY	24
12	VEE / PJN / / 2 * TUI CM112735 – OTOPY - 18M - 020Y- 010M – 6Y- O10M – 2Y- OM-1KBY- OM – OSY	28
13	VEE / PJN / / 2 * TUI CM112735 – OTOPY-18M- 020Y- 010M –6Y-O10M –7Y- OM-3 KBY-OM- OSY	30
14	ESDA / 4 / BD120 / 3 / GTA/MXP // RUFF / FGO CMBW89M5209 - 2M - O10Y - O1OM - 1Y-OM- OSY	32
15	FALKE * 2 / BISU CMBW89M7542 – OTOPY – O30M- 23Y-O10M -2Y- OM- OSY	33
16	CNDO/R143 / / ENTE / MEXI – 2 / 3 / AEGILOPS SQUARROSA (TAUS) 14 / WEAVER CMBW89Y3496 -4Y - O10M – O10Y - 38M - 2Y- OM - 3KBY - OM-OSY	40
17	KT / BAGE / / FN /U/3/ BZA /4 / TRM / 5 / ALDAN / 6 / SERI / 7 / YR / 8 / OPATA CRG1381-I-2Y-1B-OY-OY-OSY	49
18	CROC –I / AE .SQUARROSA (205) / / BORL95 CIGM90.250 - 4Y - 3B - 3Y – OB	50

Diammonium Phosphate (DAP) fertiliser was applied at the rate of 130 kg/ha. After 27 days or during the 3-6 leaf stage of the weeds, the nurseries were sprayed with Buctril M.C. herbicide at the rate of 1.35 l/ha to control broad leaved weeds. Chemical weed control was supplemented with hand weeding to control grass weeds and other weeds not controlled. At tillering stage the insecticide metasystox was applied at the rate of 1 ltr/ha to control Russian wheat aphid and other cereal aphids. Agronomic data such as tillers per plant, number of spikelets per spike, ear length, number of days to heading and physiological maturity, plant height, kernel weight, harvest index and yield per plot were obtained as described in the yield trial. Yield per hectare was calculated from yield per plot. Before maturity the performance of entries were assessed visually and classified as having good, medium or poor performance depending on how appealing they were. The rating of tolerance was based on phenotypic appearance on a scale of 1 to 5 (Pecetu and Annicehianco , 1990). Those that had very poor grain set with shrivelled grains and were un-appealing to the eye scored 1 while those that were appealing to the researcher's eye and had good stand with plum grain and good agronomic plant type scored 5. The yield of entries relative to the check was obtained. This was calculated by getting the percentage of entries yield over the mean yield of the Duma check used in the experiment.

The correlation analysis between variables was performed in each environment and when the environments were combined.(SAS, 1985). Yields were ranked in each

location and an overall mean yield across locations was calculated and a rank was given to each entry. Selection were based on the score of the drought tolerance and the their performance with respect to the check. Entries, which performed better than the check in all the environments, were selected. Also entries which scored three and above and yielded better than the check in two out of the three environments were selected. The pedigree of selected entries is presented in appendix D.

3.5 DATA ANALYSIS

The data obtained from yield trial were subjected to analysis of variance (ANOVA) for each environment (experiment at one location in one season) and combined over environments (experiment at three environments) using the mixed effect model as described by Steel and Torrie (1980). The analyses were done using SAS computer package (SAS, 1985). The difference at $p < 0.05$ and $p < 0.01$ probability levels of significance were reported. Where ANOVA showed significance, genotype means were compared using least significant difference (LSD) test. Lsd was used because the interest was first the significance difference and how different are the new lines compared with commercial checks. There was no need to compare the entries among themselves. Stability analyses were also determined using regression methods as proposed by Ebehart and Russell (1966) and by use of relative yield as proposed by Yau and Hamblin (1994). Regression coefficient (b) and deviation from regression (sd) were obtained by regression of the mean of each genotype in the

respective environment to the mean of all genotypes in an environment (environmental index). The regression coefficient (b) values were tested for difference from unity using a t-test. Based on regression parameters the slopes of linear response equations are used as index of drought resistance. Correlation among the means of the variables was performed for all the variables in specific environments and also when the environments were combined. Significance was reported at $p < 0.05$ and $p < 0.01$ levels. Genotypes stress tolerance was also estimated by mean yield and kernel weight per se in the three environments.

Selection was done using relative performance of entries with respect to the check. Entries that yielded higher than the check varieties were selected. Genotypes were also evaluated in the nursery on the basis of visual observation that was therefore subjective. The data obtained from the screening nursery was used to select lines, which were potentially useful as drought tolerant cultivars and/or as parents in a breeding program Genotypes stress tolerance was also estimated by mean yield and kernel weight per se in the three environments.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 YIELD TRIAL

In this trial a number of agronomic attributes were measured as an indicator of crop performance in semi-arid environments. Among the attributes measured were tillers/plant, spikelets/spike, plant height, ear length, number of days to heading and maturity, above ground biomass, harvest index, kernel weight, grains per head and actual grain yield.

4.1.1 Tillers per plant

During the first season in Katumani, tillers per plant did not exhibit any genotypic effect due to drought (Table 2). However, during the second season in Katumani and in Elementaita, there was a significant effect of genotypes on tillers per plant (Table 2). The means, standard error and coefficient of variation are presented in Table 4,5 and 6). There was a higher variation (C.V. = 24.16%) in the first season as compared to the second season (C.V=15.74%) and Elementaita with a coefficient of variation of 11.97%. Tillers per plant in Katumani during the first season ranged from 2.2 to 4.3 with a mean of 3.2 (Table 3). During the second season the ranges were from 2.4 to 4.5 with a mean of 3.2 while in Elementaita, tillers per plant ranged from 1.8 to 3.7 with an average of 2.8 tillers per plant (Table 5). Two entries (no 8 and 11) were not significantly different from entry number 16 which had the highest number of tillers per plant in the second season in Katumani. Fourteen entries were not significantly different from the entry number 15 which had the lowest number of tillers

per plant (Table 4). In Elementaita, four entries were not different from entry number 7 which had the highest number of tillers per plant. Two entries (No's 16 and 12) were similar with Ngamia which had the lowest number of tillers per plant (Table 5). Generally, the mean number of tillers per plant in Katumani during the first season was higher than the mean number of tillers per plant during the second season and in Elementaita. However, the mean number of tillers per plant in the first and the second season were not significantly different (Table 9) indicating that the number of tillers per plant is mainly as a result of the genetic potential of the lines. Combined over the three environments the mean number of tillers per plant was 3.1 with entry number 16 having the highest number of tillers per plant in two out of the three environments.

Combined across locations, the analysis of variance showed differential response due to genotype, location as well as location by genotype interaction (Table 6). Ngamia was the variety with the lowest head-bearing tillers per plant. However, it was not significantly different from nine other entries (Table 7). Out of the eighteen entries, eight genotypes had a higher number of tillers per plant than the overall mean. Entry number 16 which had the highest mean number of tillers per plant was not significantly different from six other entries (Table 7). The number of tillers per plant is one of the main yield components. Various authors have observed variation in tiller numbers among genotypes (El Hafid *et al.*, 1998 a; Kore and Ayiecho, 1996; Tanner *et al.*, 1996; Schonfield *et al.*, 1988; Stark and Longley, 1986). Other authors have shown that drought tolerant and susceptible genotypes do not necessarily have difference in tiller numbers. Schonfield *et al.* (1988) while working with two wheat

varieties reported that number of tillers per plant and rate of tiller development in the growing season were similar for both susceptible and tolerant varieties and hence the difference in drought tolerance were not caused by difference in tiller formation. Kinyua *et al.* (1994) also reported that number of tillers per plant did not vary significantly among drought tolerant and drought susceptible genotypes.

Factors that affect tiller number per unit area include seed rate, seed bed preparation, sowing depth, soil moisture condition at sowing and after, seed germinability, bird or insect damage and tillering capacity of varieties (Osmanzai *et al.*, 1988). Seedbed preparation sowing depth and seed rate were the same for all genotypes and were carried out as recommended (Arama *et al.*, 1997). The observed variation in number of tillers per plant among genotypes in this study was due to tillering capacity of genotypes and the environmental condition particularly moisture status at sowing and during the growing period. Drought condition during sowing may affect stand significantly even if agronomic practices are used correctly (Osmanzai *et al.*, 1988). The non-significant variation among genotypes in Katumani during the first season indicates that the moisture status of the soil did not affect expression of tillering capacity of the said lines.

During the first two months of the growing season the crops receives rainfall (119 mm) suggesting that, genotypes accumulated large biomass thus depleted residual soil moisture late in the season when they had expressed their genetic potential in terms of the number of tillers per plant. Similar results were recorded by Schonfield *et al.* (1988). In conditions of reduced moisture, the rate of leaf emergence is affected, which

will modify the leaf area. The plasticity of leaf area helps genotypes to have control over water use. The degeneration of existing tillers and total cessation of the appearance of new tillers becomes an important factor in limiting leaf area under drought stress.

The first season in Katumani experienced more degeneration of tillers as compared to the second season as shown by the lower mean number of tillers per plant (Table 2). The significant G x E interaction of tillers per plant across environments indicates that the intensity of drought or water stress was not the same for all environments and therefore genotypes expressed their tillering capacity with respect to water stress experienced. This is because the rainfall received during tillering in the first season was less 110 mm as compared to the second season Blum et al. (1990) reported similar results. Tillers play a central role in the recovery from early season drought. When drought stress does not result in total plant death the final crop, consist of tillers that were either subjected to drought stress or appeared soon after recovery. In early season drought, high tillering potential with genetic plant plasticity for its expression provides the plant with a mechanism of buffering the environmental variation.

Table 2: Mean squares values for yield and yield components of 20 bread wheat genotypes grown in Katumani and Elementaita in 1998/1999.

Variable	Source	Df	Katumani		Elementaita
			Season 1	Season 2	
Yield (g/plot)	Genotype	19	2237.85**	14298.36**	3876.71*
	Replicate	2	7827.54**	19303.19**	15296.71**
	Error	38	918.05	3060.37	1840.80
Tillers / plant	Genotype	19	1.059ns	0.769**	0.811**
	Replicate	2	3.629**	1.548**	0.015ns
	Error	38	0.603	0.249	0.113
Spikelets /spike	Genotype	19	1.896ns	2.589**	3.850**
	Replicate	2	6.432*	1.867ns	3.841ns
	Error	38	1.268	0.777	1.128
Plant height (cm)	Genotype	19	62.67 **	70.02**	50.83**
	Replicate	2	33.89 ns	5.77 ns	9.87ns
	Error	38	11.96	9.66	6.99
Ear length (cm)	Genotype	19	0.811**	0.912**	0.357ns
	Replicate	2	1.216**	1.016	0.092ns
	Error	38	0.148	0.210	0.424
Days to Maturity	Genotype	19	36.396**	10.80**	-
	Replicate	2	50.467**	3.95ns	-
	Error	38	8.572	2.99	-
Above ground biomass (t/ha)	Genotype	19	12133.25 *	169363.73 **	93452.98 ns
	Replicate	2	36507.92 **	68258.24ns	496235.00 **
	Error	38	6159.23	50964.82	74064.82
Harvest index	Genotype	19	0.002 *	0.004 *	0.006 *
	Replicate	2	0.007 **	0.008 *	0.013 *
	Error	38	0.001	0.002	0.003
Kernel weight (g)	Genotype	19	53.68 **	29.73 **	24.34 **
	Replicate	2	5.59 ns	8.88 ns	8.86 ns
	Error	38	2.38	6.74	4.48
Grains per head	Genotype	19	-	81.58ns	83.10 **
	Replicate	2	-	24.09ns	15.37 ns
	Error	38	-	49.31	29.88
Days to heading (from planting)	Genotype	19	-	42.36 **	-
	Replicate	2	-	7.22 *	-
	Error	38	-	1.62	-

* ** Indicates significance at $p < 0.05$ and $p < 0.01$ respectively. ns =Not significant.

Table 3 : Mean values of agronomic characteristics of 20 wheat genotypes grown in Katumani Kenya during (1998/1999).

Entry No.	Tillers/ Plant	Spikelets / Spike	Days to maturity	Plant height(cm)	Ear length (cm)	AGDM t/ ha	Harvest index	1000 Kernel weight(g)
1	2.90	10.50	94.66 cde	40.33 ghi	6.03 g	1.22 def	0.237 ef	27.79 g
2	2.67	11.60	101.0 a	39.73 hi	6.90 efg	1.10 ef	0.240 def	30.36 def
3	3.10	13.20	96.33 a-d	54.23 a	7.50 b-e	1.55 abcd	0.289 a-d	35.69 bc
4	2.86	11.90	99.66 ab	43.56 d-h	7.60 bc	1.19 def	0.225 f	29.57 d-g
5	2.53	12.96	97.33 abc	42.26 e-I	6.93 d-g	1.25 def	0.277 a-e	29.53 d-g
6	3.43	12.46	99.66 ab	47.36 b-e	7.43 b-f	1.31 b-f	0.283 a-e	34.28 c
7	2.63	13.40	93.00 c-f	48.60 a-d	7.56 bcd	1.48 a-e	0.313 ab	29.15 d-g
8	2.20	11.76	90.00 ef	47.26 b-f	7.16 c-g	1.58 abcd	0.287 a-d	40.31 a
9	4.00	12.43	89.33 f	49.30 abc	6.96 c-g	1.76 a	0.326 a	40.48 a
10	3.80	12.00	97.00 a-d	40.33 ghi	6.90 efg	1.34 b-f	0.265 b-f	29.51 d-g
11	3.60	13.33	95.30 bcd	49.50 abc	8.36 a	1.69 ab	0.301 abc	38.04 ab
12	2.56	12.86	96.66 a-d	37.07 I	6.83 fg	1.67abc	0.279 a-e	27.84 fg
13	3.00	12.23	96.33 a-d	44.60 c-h	7.10 c-g	1.58abcd	0.293 abc	28.70 d-g
14	3.33	11.50	100.66 a	41.63 f-I	7.43 b-f	1.03 f	0.259 c-f	30.40 de
15	3.80	12.50	100.66 a	40.43 ghi	6.70 g	1.27 c-f	0.252 c-f	31.06 d
16	4.30	12.53	92.33 def	44.16 c-h	7.06 c-g	1.42 a-f	0.258 c-f	30.12 d-g
17	4.20	13.43	94.33 cde	46.26 def	7.96 ab	1.38 a-f	0.267 b-f	34.19 c
18	2.80	12.16	92.33 def	48.16 bcd	7.43 b-f	1.35 b-f	0.285 a-e	38.25 a
Duma	3.40	11.56	92.66 c-f	45.70 c-g	7.96 ab	1.42 a-f	0.287 a-d	28.35 efg
Ngamia	3.13	13.50	96.33 a-d	52.80 ab	7.06 c-g	1.53 abcd	0.283 a-e	29.73d-g
Mean	3.21	12.39	95.78	45.17	7.25	1.41	0.275	32.17
C.V.	24.16	9.08	3.06	7.66	5.32	17.45	10.982	4.79
LSD (0.05)	NS	NS	4.84	5.72	0.64	0.41	0.05	2.55

Means having the same letter within a column are not significantly different. AGBM = above ground biomass. NS-Indicates non significance

4.1.2 Spikelets per spike

Spikelets per spike showed a highly significant difference in two out of three locations in which the trials were carried out. It was in Katumani during the first season that the number of spikelets per spike among genotypes was not significant (Table 2). The combined analysis of variance yielded a highly significant difference between genotypes and locations but genotype by location interaction was only significant at 5% ($p < 0.05$).

The first season in Katumani exhibited the highest variation in the mean number of spikelets per spike (12.39) but was not significantly different from that of Elementaita (12.64) (Table 9). The second season in Katumani had the highest mean number of spikelets per spike (13.65). The coefficient of variation of genotypes in all the three environments were less than 10 % (Table 4 and 5). In terms of relative ranking of the means across locations, entry no 11 had the highest number of spikelets per spike (14.15). It was also not significantly different with eight other entries (Table 7). This entry was ranked second in the number of tillers per plant (Table 7). Entry number 1 that had the lowest number of spikelets per spike (11.48) was not significantly different from six other genotypes including Duma (Table 7). Duma and Ngamia generally, had low number of spikelets per spike.

In Katumani during the first season, spikelets per spike ranged from 10.6 to 13.5 with a mean of 12.4 (Table 3). It ranged from 11.9 to 15.2 with a mean of 13.7 in the second season (Table 4) while in Elementaita, the average number of spikelets

per spike was 12.6 with a range of 10.9 to 14.4. (Table 5). During the second season at Katumani, the entry with the highest number of spikelets per spike was not significantly different from ten other entries. Four entries (Duma included) were not significantly different from entry number 18, which had the lowest number of spikelets per spike (Table 4). Also, in Elementaita, ten entries were not significantly different, from entry number 5 which had the highest number of spikelets per spike and eight entries were statistically the same with entry number 6 which had the lowest number of spikelets per spike (Table 5). The above results indicate that the number of spikelets per spike was affected by genetic make up of the genotypes and the environment. Similar results were observed by Shalembi and Wright, (1992). In addition, the low coefficient of variation among genotypes (less than 10%) in all environments attests to this.

The number of spikelets of most genotypes were not similar across environments. Only entry number 12,13 and Duma had consistent ranking. The effect of water stress on the number of spikelets per spike depends on the period it occurs. When water stress occurs at late vegetative phase or during late internode elongation, the development of wheat spike is impaired. Death of florets occurs at the terminal and basal ends of the spike due to male sterility caused by water stress. Craufurd *et al.* (1993) observed that water stress during heading had a significant effect on the number of spikelets per spike. Ten entries were not significantly different from entries having the highest number of spikelets per spike in Katumani during the second

season and in Elementaita indicating that water stress had minimal influence on this trait in these environments.

In Elementaita the genotypes experienced low moisture status during heading stage since most of rainfall received (99 mm) was lost through evaporation (50 mm). Therefore, the observed variation in genotypic performance was mainly due to difference in response to early drought stress. The temperatures were within the optimum range (a range of 26-28^{0}C during the growing period). The favourable temperature regime influenced the length of spike growth period and hence the number of spikelets. The number of viable florets and potential grain yield depends on moisture status during the grain filling and the rate of remobilization of stored assimilates (El Hafid *et.al.*, 1998c). This is in agreement with the findings of Reynolds and Acevedo (1992) who contends that wheat crop is most sensitive to water stress and temperature at spike development and flowering growth stage. Therefore, if spike growth coincides with coolest periods of the crop cycle, realization of yield potential can be improved.

4.1.3 Ear length

The analyses of variance of this trait in the three environments are presented in Table 2. The results indicate that the ear length was significantly different among varieties in Katumani during both seasons. There was no varietal effect on ear length in Elementaita (Table 2). A combined analysis of variance across locations is presented in Table 6. There was differential response of this trait to variety and

location but the genotype by environment interaction was not significant. This indicates that the response to change in environment of this trait is similar for all genotypes. Entry no 11 had consistently longer ears in all the three environments. Pooled over seasons, the mean ear length of this entry (8.5 cm) was also significantly different from all the other genotypes (Table 7). Similarly, entry number 1 which had the shortest ear length in all the three environments and combined over seasons was also different from all the other entries (Table 7). The variation in ear length in Elementaita ranged from 6.7 cm to 8.3 cm. In Katumani during the first season, the ear length ranged from 6.0 cm to 8.4 cm while in the second season the length of ears ranged from 7.0 cm to 9.2 cm. Generally, the mean ear length was higher in Katumani during the second season. This environment was significantly different from the other two environments (Table 9). Combined across locations, the average length of head, was 7.5 cm. The above results show that genotypes expressed their potential ear length. This is because when we compare Katumani in season 1 with Elementaita, it is seen that the mean ear lengths in two environments were not significantly different. The significant difference in ear length during the second season in Katumani can be attributed mainly to interplay of hormonal factors and to a lesser extent on genetic factors. This can occur due to the influence of water stress on hormones. Under water stress, there is accumulation of abscisic acid (ABA) . This leads to stomatal closure and reduced transpiration. Consequently photosynthesis, leaf expansion and ear size reduces. The consistent ranking of genotypes in terms of the length of ears coupled with non-significant genotype by environment interaction,

indicate that genotypes responded uniformly to change in environment. The performance of varieties in terms of ear length can thus be attributed mainly to their genetic make up.

4.1.4 Plant height

Plant height is of general interest due to its effect on lodging and straw yield. The analysis of variance for plant height, yielded highly significant differences among genotypes in all the three environments (Table 2). In the first season at Katumani, plant height ranged from 37 to 54 cm with a mean of 45 cm. In Katumani during the first season entry number 3 was the tallest. However four other entries, Ngamia inclusive were not significantly different from this entry. The shortest entry number 12 was statistically similar in height with other six entries (Table 3). In the second season the height ranged from 52 to 67 cm with a mean of 59 cm. During the second season, eight genotypes including Duma and Ngamia were statistically taller varieties while nine entries were not significantly different from the shortest (entry number 6) genotype (Table 5). The range in Elementaita was 36 cm to 50 cm with most genotypes having a height of around 42 cm. In Elementaita, Duma, Ngamia and entry number 13 were not significantly different with entry number 14, which was the tallest (mean height = 50.26 cm) as compared with five entries which were statistically similar with the shortest entry (Table 6). Most genotypes in Elementaita were shorter while in Katumani (second season) most genotypes were taller.

Table 4. Mean values of 20 genotypes grown during the second season in Katumani, Kenya (1999)

Entry No.	Tillers/ Plant	Spikelets/ spike	DTPM*	Plant height(cm)	Ear length(cm)	AGBM t/ha	Harvest index.	Days to Heading	Kernel weight (g)	Grains /head
1	3.10 c-f	12.30 ef	94.00 bc	52.36 f	7.03 h	2.76 b-f	0.230 abc	54.66 fg	28.63 de	20.17
2	3.23 b-f	13.93 a-d	92.66 b-e	55.6 def	7.66 e-h	2.82 b-e	0.227 a-d	55.33 ef	28.99 cde	30.11
3	2.60 ef	14.13 a-c	94.66 abc	58.03 cde	8.76 a-d	2.59 c-f	0.199 b-e	57.33 b-e	29.94 bcd	24.93
4	3.10 c-f	14.53 ab	92.33 cdef	55.93 def	8.26 b-e	2.43 ef	0.150 de	59.00 b	24.75 ef	24.16
5	3.23 b-f	14.76 ab	92.00 c-f	55.36 def	8.10 d-g	3.44 b-e	0.216 a-d	56.66 c-f	26.49 def	32.16
6	3.20 b-f	13.76 b-d	97.00 a	51.93 f	9.23 a	1.63 f	0.238 abc	63.33 a	27.41 def	27.60
7	2.63 ef	14.36 ab	93.66 bc	56.66 def	7.96 efg	4.85 a	0.173 cde	57.33 b-e	26.61 def	26.13
8	3.83 abc	12.70 c-f	89.66 f	65.10 ab	8.13 c-g	3.86 ab	0.270 ab	52.00 hi	35.70 a	34.00
9	3.5 bcd	12.53 d-f	92.66 b-e	64.03 ab	7.63 e-h	3.72 abc	0.284 a	49.66 j	33.99 ab	35.86
10	3.36 b-d	14.03 a-c	92.66 b-e	55.03 ef	8.03 d-g	2.43 ef	0.199 b-e	56.66 c-f	26.36 def	28.90
11	3.96 ab	15.23 a	92.66 b-e	66.60 a	8.86 abc	3.07 b-e	0.203 b-e	52.33 hi	27.73 def	23.86
12	2.86 def	14.10 abc	90.33 d-f	53.70 ef	7.40 gh	2.50 def	0.227 abc	52.66 ghi	28.21 def	25.66
13	3.00 def	13.53 b-e	92.33 c-f	62.86 abc	7.70 e-h	3.82 ab	0.188 cde	58.66 bc	24.06 f	32.33
14	3.00 def	13.96 a-d	95.33 ab	55.20 def	8.93 ab	2.86 b-e	0.139 e	62.00 a	24.26 ef	19.30
15	2.43 f	14.33 ab	92.66 b-e	60.33 bcd	7.90 efg	2.32 ef	0.268 ab	53.00 gh	24.93 ef	26.96
16	4.53 a	14.03 abc	94.66 abc	57.03 def	7.50 fgh	3.04 b-e	0.203 b-e	58.33 bcd	28.09 def	28.93
17	3.16 b-f	13.46 b-e	92.00 c-f	64.03 ab	8.10 d-g	3.64 bcd	0.236 abc	52.00 hi	28.30 de	23.96
18	3.10 c-f	11.93 f	90.00 ef	63.96 ab	7.83 efg	3.84 ab	0.265 ab	50.66 ij	33.56 abc	25.56
Duma	2.93 d-f	11.93 f	93.00 bcd	63.56 ab	7.80 efg	2.99 b-e	0.204 b-e	56.33 def	27.29 def	40.70
Ngamia	2.53 f	13.43 b-e	89.66 f	65.26 ab	8.16 c-f	3.89 ab	0.232 abc	51.33 hij	27.37 def	24.81
Mean	3.16	13.65	92.70	59.13	8.05	3.11	0.217	55.46	28.13	27.78
MSE	0.249	0.777	2.985	9.659	0.210	50964.82	0.0019	1.620	6.735	49.306
LSD (0.05)	0.825	1.46	2.86	5.137	0.758	1.17	0.07	2.10	4.30	NS
C.V	15.74	6.46	1.86	5.26	5.69	22.65	20.32	2.29	9.22	25.27

Means having the same letter within a column are not significantly different. AGBM=above ground biomass.

* DTPM- Number of days from planting to physiological maturity.

The pooled analysis of variance over locations showed significant varietal and locational difference as well as genotype by location interaction (Table 6). The significant genotype by environment interaction is reflected by the difference in relative ranking of genotypes (Tables 3, 4, and 5). In a combined mean separation, Ngamia was the tallest variety but was not different from three other entries. Entry number 12 was the shortest though not significantly different from three other entries (Table 7). The height of genotypes across locations ranged from 43 cm to 55 cm with a mean of 49 cm.

Under conditions of uncertain amount of precipitation, a line may grow tall and lodge under good moisture condition or be short in the dry season. In environments of low nutrients coupled with abiotic stresses such as water stress, plants are often stunted in growth. The variation in plant height may become one of the causes of variation in grain yield. Plant height has been observed to vary among genotypes (Kinyua and Ayiecho, 1992; Hucl and Baker, 1989). From the above results, it is observed that genotypes which are short in good environments, were relatively short in all the test environments while those which are tall behaved so in all the test environments. This indicates that genetic potential of genotypes played a role in the expression of this trait. For example entries number 11,18 and 20 were taller varieties in all the three environments as compared to entry number 1,10, and 12 which had short plant heights in all the environments. The ranking of genotypes however were variable indicating that apart from the genetic make up of genotypes,

the environmental conditions in the test sites were variable, thereby influencing the expression of plant height among genotypes. This was depicted by the significant G x E interaction.

The height of a plant determines the amount of stored assimilates. Genotypes store assimilates in the stem. The reserve accumulation and storage capacity in the stem strongly depend on the growing conditions before anthesis. Normally under drought, stem length is important in determining reserve storage. Borell *et al.* (1993) observed that the Rht1 and Rht2 dwarfing genes of wheat were found to reduce storage by 35% and 39% respectively as a consequence of a 21% reduction in stem length. Lodging was not a problem in any of the lines. This is mainly because of lower mean heights of genotypes. The range of 68-100 cm has been observed (Mohamed, 1992) for wheat under irrigation and a range of 38-90 cm for Durum wheat under naturally water logged highland vertisols (Teseme *et al.*, 1992). Mean heights across various environments can sometimes be higher. On average in high potential areas plant heights ranges from 100 cm to 150 cm. Geleta *et al.* (1992) observed a range of 88-120 cm when varieties were grown under rain-fed conditions at nine locations representing a range of environments. Plant heights ranged from 43- 59 cm indicating that plants were relatively short. This means that plant heights were not expressed to their full potential. In this experiment, lodging was not observed among the lines tested.

4.1.5. Above ground plant biomass

Results of the analysis of the above ground biomass are presented in table 2. In Katumani, the range of biomass yield range was low ranging from 1.0 to1.8 t/ha in the first season and from 1.6 t/ha to 4.9 t/ha in the second season. In Elementaita, biomass yield ranged from 1.4 t/ha to 3.7 t/ha. Averaged over locations, the range was 1.6 t/ha to 2.8 t/ha. Only Elementaita showed a non significant difference in genotype for this trait (Table 2). During the first season in Katumani six genotypes yielded higher but non significant biomass than Duma and Ngamia (Table 3) but in the second season, Ngamia was ranked second in biomass yield with Duma being ranked seven (Table 4). During the first season in Katumani ten genotypes were not significantly different with entry number 9, which had the highest biomass yield (1.76 t/ha). Entry number 14 which had the lowest biomass was not significantly different with eleven varieties (Table 3). In the second season entry number 7 had the highest biomass. It was however not statistically different from five other entries including Ngamia. Six genotypes were not significantly different with entry number 6 that had the lowest above ground biomass at harvest (Table 4). Across location, analysis of variance yielded a significant difference in this trait for variety, location as well as variety by location interaction (Table 6). The three environments were significantly different from one another (Table 9) with season two in Katumani yielding the highest biomass (3.11 t/ha). The significant G X E interaction is reflected in the differential

ranking of genotypes (Table 3, 4 and 5). G x E interaction could also be shown by the difference in stability of genotypes across environments.

In the combined mean separation both Ngamia and Duma, were ranked eight (Table 8). However, nine other genotypes were not significantly different from entry number 13, which gave the highest plant biomass at harvest (Table 7). On the other hand eight entries were statistically similar with entry number 6 which had the lowest biomass. The above ground dry matter is a function of water transpired by the crop and the efficiency with which the water is used (WUE). Therefore maximizing the above ground dry matter under water limited conditions is first achieved by maximizing its components: water transpired by the crop and the water use efficiency (WUE). Reducing surface water evaporation relative to transpired water is a mechanism that may increase total amount of water transpired and hence yield.

Table 5: Mean separation of yield components of 20 wheat genotypes tested in a yield trial in Elementaita, Kenya during the growing season of 1999

Entry No	Tillers/ Plant	Spikelets/ spike	Plant height (cm)	Ear Length(cm)	AGDM t/ ha	Harvest index	1000 Kernel weight (g)	Grains /head
1	3.33 a-d	11.66 def	35.56 I	6.70	1.56	0.232 a-f	29.64 g	21.60 fg
2	2.76 efg	14.43 a	43.60 c-g	7.13	2.40	0.199 c-f	30.49 d-g	36.26 abc
3	2.80 d-g	11.10 ef	41.50 e-j	7.23	2.59	0.195 c-f	32.31 b-f	28.53 c-g
4	3.03 b-f	12.83 a-e	44.76 b-f	7.20	2.92	0.194 c-f	32.25 c-f	40.73 a
5	2.53 fgh	14.43 a	38.96 h-l	7.66	1.98	0.221 b-f	29.69 efg	33.93 a-e
6	3.40 abc	10.93 f	42.33 d-I	7.30	1.92	0.239 a-f	31.27 d-g	28.36 c-g
7	3.73 a	12.93 a-d	43.00 c-h	7.13	2.04	0.314 a	32.54 b-f	27.53 c-g
8	2.80 d-g	11.46 def	42.36 d-I	7.10	2.21	0.286 ab	37.73 a	26.33 d-g
9	3.06 b-f	11.93 c-f	38.53 i-l	7.50	2.42	0.197 c-f	34.91 abc	26.93 d-g
10	3.00 b-f	13.96 ab	36.83 kl	7.40	2.31	0.172 ef	29.65 g	39.53 ab
11	3.06 b-f	13.90 ab	45.70 b-e	8.33	2.57	0.157 f	33.91 bcd	30.20 c-f
12	2.03 hi	13.66 abc	37.40 j-l	7.00	1.43	0.233 a-f	28.45 g	30.80 b-e
13	3.23 a-e	12.23 b-f	46.50 a-d	6.83	3.01	0.172 ef	29.29 g	31.73 a-e
14	2.86 c-g	11.73 def	50.26 a	7.10	3.71	0.179 ef	33.16 b-e	27.33 c-g
15	3.50 ab	12.76 a-e	41.23 f-j	7.40	1.81	0.268 a-d	28.40 g	25.46 efg
16	2.10 hi	13.83 ab	40.30 g-k	7.56	1.63	0.255 a-e	30.13 efg	35.13 a-d
17	2.33 gh	13.13 a-d	37.13 j-l	7.03	2.01	0.253 a-e	32.38 b-f	31.46 b-e
18	2.43 gh	12.73 a-e	45.33 b-f	7.46	2.81	0.276 abc	37.91 a	29.13 c-g
Duma	2.43 gh	11.13 ef	48.20 ab	7.23	2.54	0.190 def	35.76 ab	21.00 g
Ngamia	1.76 I	12.03 c-f	46.76 abc	7.16	2.32	0.235 a-f	33.80 bcd	34.66 a-d
Mean	2.81	12.64	42.32	7.28	2.31	0.223	32.18	30.34
MSE	0.113	1.128	6.99	0.424	74064.8	0.0025	4.483	29.879
LSD	0.56	1.76	4.37	NS	NS	0.084	3.50	9.04
C.V	11.97	8.40	6.25	8.96	36.83	22.74	6.58	18.02

Means having the same letter within a column are not significantly different. AGBM = above ground biomass.

Genetic variation of cereals in leaf area display may increase the rate at which full ground cover is achieved. When this is achieved, the rate of evaporation is reduced. Fertilization particularly supply of nitrogen fertilizers allows higher relative growth rate such that plants will grow vigorously, attain canopy closure earlier, and therefore reduce water loss through evaporation. The observed variation in genotypes in terms of their dry matter is contributed by the differential capacity of genotypes to grow vigorously particularly under drought conditions and their better efficiency in water use. The availability of water to wheat genotypes determines dry matter production. Aggarwal and Sinha (1983) observed that water availability on a fully charged soil profile of about 20 cm is enough to produce 800 g/m^2 dry matter. The lines which yielded higher biomass than Duma and Ngamia, shows that they had good if not better water use efficiency than the recommended varieties. This was possibly due to better rooting system particularly in terms of root mass, which enabled them to extract more water.

Factors that maintain transpiration under stress will favour continued dry matter production. However, over the life of a plant optimization rather than maximization of water use is required especially during prolonged periods of stress. Optimization implies some regulation of the use of a limited amount of soil moisture throughout the crop season or the maximization of the soil moisture extraction when rainfall is expected to follow. In semi arid areas some of the water is deeply stored in the soil and cannot be used by the plant. Genotypes with a deeper root system can extract additional amount of water and therefore could improve the total biomass

production. When a plant is subjected to decreasing water potential, its response is to switch to reproductive phase. In the process, they reduce the sinks. Senescence is a common phenomenon in plants subjected to drought. From the above results, it is observed that the average plant biomass was low compared to what is obtained among wheat genotypes under fully irrigated conditions. Vigorous early growth is achieved depending on the genetic make up of varieties. High dry matter yield before anthesis is achieved resulting in improved grain yield. Moisture stress conditions are associated with high temperatures. Under these conditions respiratory rates are markedly increased leading to low net assimilation and dry matter accumulation. Also the rate of physiological development is increased and the onset of the process of senescence occurs more quickly. Low water status and high temperature results in an increase in saturation vapour pressure deficit of the atmosphere. This increase leads to a reduction in the efficiency of water use because of reduced carbon fixation. Genotypes with high biomass have high storage reserves and if they can be able to convert the reserves in their dry matter into grain yield the better as the ultimate interest is harvest index and economic yield. In Elementaita above ground biomass among genotypes was not significant. Genotypes utilized the available soil water and thus had vigorous growth. Towards maturity, the genotypes received water therefore the plant biomass was not affected much. Yield was also not affected much since the difference in yield among genotypes was only significant at $p < 0.05$ (Table 2).

Table 6: Combined analysis of variance for yield and yield components of 20 bread wheat genotypes grown in three sites in Kenya during the 1998/99 growing season

Variables measured	Source	Genotype	Location	Replicate/location	Genotype x location (G x L)	Error
	df	19	2	6	38	114
Tillers / plant		0.946 **	2.895 **	1.731**	0.847 **	0.321
Spikelets / spike		5.111 **	26.63 **	3.047 *	1.612 *	1.058
Plant height (cm)		111.70 **	4859.5 **	16.512 ns	35.907 **	9.537
Ear length (cm)		1.342 **	12.52 **	0.775 **	0.369 ns	0.261
Grains / head		70.843 *	186.441 *	19.729 ns	92.249 **	39.330
Above ground biomass (g/plot)		109442 **	4429906**	200333.7 **	83476.02 **	43600.433
Harvest index		0.006 **	0.060 **	0.010 **	0.003 *	0.0018
Kernel weight (g)		84.023 **	315.077 **	7.776 ns	11.763 **	4.493
Days to maturity		29.921 **	285.208 **	27.208 **	17.279 **	5.779
Yield (g/plot)		11077.65 **	119675.1 **	14142.48 **	4713.20 **	1919.73

* ** Indicates significance at $p < 0.05$ and $p < 0.01$ respectively. ns =Not significant; d.f- degrees of freedom.

4.1.6 Days to 50 % heading

The analysis of variance for this trait is presented in Table 2. In Katumani during the first season the data collected was not reliable, as there were many off types. In Elementaita this type of data was not collected due to logistic problems. Therefore the findings and recommendation of this trait are only applicable to Katumani. The results indicate that in Katumani during the second season, the effect of genotypes on the number of days from planting to 50 % heading was highly significant. Genotypes headed between 50 to 63 days after sowing, with most varieties heading around 55 days (Table 4). Two genotypes headed earlier than Ngamia but the difference were not significant. These entries are entry number 9 and 18. Out of ten varieties which headed earlier than Duma only eight were significantly different from it in their heading dates and of the nine which headed later than Duma, only four were significantly different from it (Table 4). Therefore, Duma could be classified as a medium heading variety in this study. Two entries (Entry number 6 and 14) were latest heading genotypes. They headed at 63 and 62 days after planting respectively (Table 4).

Plants vary in the duration of their growth period depending on their genetic make up and on the environmental conditions the plant experiences in the field. Phenology has a powerful effect on plant growth response to drought and productivity under stress. Water stress delays the developmental events because of inhibition of growth. Both the time duration from spike initiation to spike emergence increases under water stress while the rate of leaf appearance decreases accordingly

(Blum, 1996). The delaying effect of drought on flowering in wheat could perhaps be because of abscisic acid (ABA). However ABA could delay or advance flowering depending on the species and the time when ABA is in effect (Blum, 1996).

The observed variation in genotypes with respect to their heading dates is due to the effect of environment on the hormones like ABA and the intensity of water stress. High ABA accumulation when plants are stressed leads to stomata closure, reduced transpiration thus reduced photosynthesis and leaf expansion. Reduced transpiration causes plant heating thus advance the flowering and hence maturity of genotypes (Blum, 1996). The tendency of plants to accumulate ABA depends on the genetic make up of the plants as well as the sensitivity of ABA to various processes it affects (Austin, 1988). Early maturity allows the crops to avoid drought if it occurs during the last period of crop growth. It also contributes in reducing direct evaporation from the soil promoting a rapid development of leaf area. Wheat cultivars with early vegetative growth and reduced leaf area index are more suitable where the amount of available water is the more limiting factor. Under conditions of favourable moisture, late heading genotypes are more preferable since they have a longer growing period, which means that they can accumulate large biomass that is remobilised during grain filling. Early flowering genotypes will permit grain filing to occur during periods when the crop is likely to be less water stressed.

4.1.7 Days to 50 % maturity

Days to maturity was when the plants vegetative parts had dried up (loss of chlorophyll) through normal physiological process and grains reaching hard dough

stage. Days to 50 % physiological maturity showed a significant varietal difference in Katumani during both seasons (Table 2). Combined across locations, days to 50 % physiological maturity showed a highly significant difference for variety and location with variety by location interaction showing significance at 5 % level of probability (Table 7). Genotypes in the first season in Katumani took between 89 to 101 days to reach 50 % physiological maturity with most entries maturing within 96 days as compared to the second season where plants matured between 90 to 97 days. Most genotypes matured around 93 days (Table 3 and 4). Both seasons were different in the average length of time plants took to mature (Table 9)

During the first season in Katumani, entry number 9 was the earliest to mature, however, it was not significantly different with five other genotypes in the number of days they took to reach physiological maturity (Table 3). Entry number 2 which was the latest maturing variety was not significantly different with ten other genotypes, Ngamia included. In the second season Ngamia was the earliest to mature but was statistically the same with other seven genotypes in the number of days they took to mature. Entry number 6 which was latest to mature was not significantly different from three other genotypes (Table 4). When mean number of days to maturity of genotypes over environment are separated, Entry number 8 was the earliest to mature (took 89 days to reach maturity). It was not significantly different from entry number 9 and 18 both of which took 91 days to reach 50% physiological maturity. On the other hand the number of days to maturity of four genotypes was statistically similar with entry number 6 which was the latest to mature (Table 7).

Both Duma and Ngamia were early maturing varieties but Duma appeared to mature earlier than Ngamia.

In the combined analysis, maturity of genotypes ranged from 90 to 98 days with most varieties maturing within 94 days. Duma and Ngamia were not significantly different from each other on the length of their growth period (Table 7). The length of time plants take to mature is determined by the difference in genotypes and the water status of the crop during grain filling. Phenology and its modification by drought stress affects plant production under drought stress. Growth duration determines water requirements and the probability of exposure to stress both of which decrease in early maturing genotypes. Stomatal sensitivity to leaf water deficits decreases after flowering i.e. greater leaf water deficit is required to close the stomata rather than before flowering (Blum, 1996). Removal of half of the spikelets (and grain) from the wheat ear decreased stomatal conductance on the flag leaf under drought stress and retained flag leaf water status and longevity (Blum *et al.*, 1988). Thus, the presence of sufficient number of flowers or seeds in the plant signals the stomata to stay open. This signal may be hormonal. From the arguments advanced above it is evident that those genotypes that took longer time to mature had accumulated large sinks and as a result their grain filling duration was long. Water stress before flowering impairs leaf expansion. This will in turn reduce leaf area index and intercepted radiation. After flowering this reduction is mainly as a result of progressive leaf senescence. In this study most genotypes matured early indicating

that water stress induced early maturity and that these genotypes had shorter grain filling period.

4.1.8 Number of grains per head

The analysis of variance showed that, the number of grains per head was significantly different among genotypes in Elementaita but not in Katumani. Nevertheless in a combined analysis of variance, response due to variety and location was significant at $p<0.05$ with variety by location interaction being highly significant (Table 3). The number of grains in Elementaita ranged from 21 to 41 grains per head with an average of 30 grains. The coefficient of variation (18.01%) was low in this environment (Table 6) as compared with 25.28% in Katumani during the second season. The means of the two seasons were significantly different (Table 9) with an average of 28 and 30 grains per head in Katumani and Elementaita respectively. Overall, the means combined over the two sites shows that the number of grains per head ranged from 21 to 34 kernels with a grand mean of 29. Seven genotypes had a higher number of grains per head than Ngamia and Duma but were not significantly different as shown in Table 7. In Elementaita where there was significant effect of genotypes on number of grains per head, Duma had the lowest number of grains per head. However, it was not different from nine other entries (Table 5). Entry number 4 which had the highest number of grains per head was statistically the same with six entries including Ngamia.

Environmental stress affects the size of the spike by influencing the duration of apex vegetative phase and spikelet development. Spike length determines the

number of florets, which will form the grains. The lower the number of spikelets, the fewer the grains This was also reported by Blum *et al.* (1989). This is because in addition to flower abortion occasioned by water stress during grain filling, some flowers might not form grains or if they form, the grains will be shriveled or poorly filled. Giunt *et al.* (1993) reported that severe water stress from seedling to maturity reduced all yield components particularly the number of fertile ears by 60 % and grain number by 48 %. Consequently, the final grain number is reduced. Scarce carbohydrate availability during grain formation is one of the main factors responsible for reduced spike fertility and lower kernel weights. On the other hand genotypes which had higher number of kernels per spike showed that even though the plants experienced water stress they still filled the developing florets and had more grains per head. Those genotypes which had more grains per head and the grains were heavy (relatively well filled and dense grains) indicate that they had a better mechanism for tolerating drought. For example, in Katumani during the second season, entry numbers 2, 8, and 9 had higher number of grains per head. These entries could still be able to fill the grains and thus they recorded higher kernel weights (Table 4). The above entries also showed similar behavior in Elementaita (Table 5). Siddique *et al.*, (1990) reported that a high kernel weight would finally result in higher yields.

4.1.9 Harvest index

The harvest index of the 20 genotypes tested in the three locations showed a significant varietal difference ($p < 0.05$) in all the environments (Table 2). In a pooled

analysis of variance, the effect due to variety and location was highly significant with genotype by location interaction yielding significance at 5 % level of probability (Table 6). Mean harvest index was more variable (c.v = 22.74%) in Elementaita followed by Katumani (c.v = 20.32%) during the second season and then the first season (c.v = 10.98%). When locations are compared, the mean harvest index in Katumani during the first season was significantly different from the mean harvest index of the second season and Elementaita (Table 9). The harvest index in Katumani ranged from 0.23 to 0.33 with a mean of 0.28 in the first season. In the second season, the range was 0.14 to 0.28 with a mean of 0.22 while in Elementaita mean harvest index ranged from 0.16 to 0.31 with a mean of 0.22. Average over environments, the harvest index ranged from 0.19 to 0.28 and had a grand mean of 0.24.

Ranking of genotypes indicated that during the first season in Katumani, five entries gave higher harvest index than Duma whereas nine entries yielded higher harvest index than Ngamia (Table 3). However, the difference in harvest index of these genotypes was not significantly different (Table 3). Entry number 4 had the lowest harvest index but was not significantly different from seven other entries. In the second season in Katumani, eleven and six other lines had a higher harvest index than Duma and Ngamia respectively with ten of them being significantly different from Duma (Table 5). Entry number 9 had the highest harvest index in both environments .

In Elementaita, the harvest index of Ngamia was not significantly different from that of the genotype having the highest harvest index. Entries number 7, 8, 9 and 18 gave high harvest indices in all the three environments but their ranking was variable. The mean harvest index across environments indicated that entry number 8 had the highest mean harvest index but it was statistically similar to eight other entries (Table 7). Entry number 4 had the lowest mean harvest index but it was not significantly different from seven other genotypes.

Harvest index provides an estimate of the conversion efficiency of dry matter to grain yield. While H.I of the same cultivars grown under optimal conditions approached and sometimes exceed 0.4, it was generally much less under drought (El Hafid *et al.* (1998 a). In this study, the mean harvest index among genotypes was 0.24. Simane *et al.*(1996) observed that harvest index ranged from 0.2 – 0.5 among the varieties pooled over moisture treatments with the drought susceptible varieties recording the lowest harvest index while the drought tolerant ones having the highest harvest indices

Table 7: Combined means separation of various agronomic traits of 20 bread wheat genotypes tested in a yield trial in three locations in Kenya during the 1998/1999 growing season.

Entry	Tillers / Plant	Spikelets / spike	Plant height(cm)	Ear length (cm)	DTPM	AGBM t/ha	Harvest index	1000 Kernel weight	Grains / head
1	3.11 b-f	11.48 f	42.75 j	6.58 g	94.33 c-f	1.85 def	0.234 c-f	28.69f-i	20.83 d
2	2.88 d-g	13.32 abc	46.31 ghi	7.23 def	96.83 abc	2.11 cdef	0.222 efg	29.84 d-h	33.44 ab
3	2.83 e-g	12.81 b-e	51.25 bcd	7.83 bc	95.50 b-f	2.24 a-e	0.228 d-g	32.65 bc	26.73 bcd
4	3.00 c-g	13.08 bcd	48.08 e-h	7.68 bcd	96.00 a-e	2.18 b-f	0.190 g	28.86 f-i	32.45 ab
5	2.76 fg	14.05 a	45.53 hij	7.56 b-e	94.66 c-f	2.22 a-f	0.238 b-f	28.57 g-I	33.05 ab
6	3.34 a-e	12.38 c-f	47.21 fgh	7.98 b	98.33 a	1.62 f	0.253 a-e	30.99 cde	27.98 a-d
7	3.00 a-f	13.56 ab	49.42 def	7.55 b-e	93.33 efg	2.79 a	0.267 a-d	29.43 e-h	26.83 bcd
8	2.94 d-g	11.97 ef	51.57 bcd	7.46 c-f	89.83 h	2.55 abc	0.281 ab	37.91 a	30.16 abc
9	3.52 abc	12.30 def	50.62 dce	7.36 c-f	91.00 gh	2.63 abc	0.269 abc	36.46 a	31.40 ab
10	3.38 a-d	13.33 abc	44.06 ij	7.44 c-f	94.83 c-f	2.03 cdef	0.212 fg	28.51 ghi	34.22 a
11	3.54 ab	14.15 a	53.93 ab	8.52 a	94.00 def	2.44 a-d	0.220 e-g	33.23 b	27.03 a-d
12	2.48 g	13.54 ab	42.72 j	7.07 f	93.50 efg	1.86 def	0.246 a-f	28.17 hi	28.23 abc
13	3.07 b-f	12.66 b-e	51.32 bcd	7.21 ef	94.33 c-f	2.81 a	0.218 efg	27.35 i	32.03 ab
14	3.06 b-f	12.40 c-f	49.03 d-g	7.82 bcd	98.00 ab	2.53 abc	0.194 g	29.27 e-I	23.32 cd
15	3.24 a-f	13.20 a-d	47.33 f-h	7.33 def	96.66 a-d	1.80 ef	0.263 a-d	28.13 hi	26.22 b-d
16	3.64 a	13.46 ab	47.16 f-h	7.37 c-f	93.50 efg	2.03 c-f	0.239 b-f	29.45 e-h	32.03 ab
17	3.23 a-f	13.34 abc	49.14 d-g	7.70 bcd	93.16 fg	2.34 a-e	0.252 a-e	31.62 bcd	27.72 a-d
18	2.77 fg	12.27 def	52.48 abc	7.57 b-e	91.16 gh	2.67 ab	0.275 ab	36.58 a	27.35 a-d
Duma	2.92 d-g	11.54 f	52.48 abc	7.66 b-e	92.83 fg	2.32 a-e	0.227 d-g	30.46 d-g	30.85 ab
Ngamia	2.47 g	12.98 bcd	54.94 a	7.46 c-f	93.00 fg	2.61 abcde	0.250 a-f	30.39 c-f	28.64 abc
Mean	3.06	12.90	48.87	7.52	94.24	2.27	0.239	30.86	29.08
C.V	20.09	8.52	8.52	7.57	2.60	32.80	19.20	7.19	20.16
Lsd	0.53	0.96	2.88	0.48	2.76	0.61	0.04	1.98	7.21

Means having the same letter within a column are not significantly different DTPM= Days to physiological maturity; AGDM = Above ground plant biomass.

Harvest index is determined by the balance between dry matter produced and hence water used and the amount of remobilized pre anthesis assimilates. If a crop exhaust most of the soil water before anthesis, little will be left for grain filling resulting in low harvest index. The observed variation in harvest index of genotypes was possibly due to the amount of non-structural carbohydrates and their remobilization. When plants senesce as a result of increased water stress, the leaf area is reduced indicating a reduction in stored assimilates and loss of sites for production of current assimilates. The result is less assimilate transfer to grains. The size of reproductive sinks and the rate and duration of assimilate partitioning to the sink therefore determines harvest index. Grain growth in cereals is supported by the transient photosynthesis (by the flag leaf and the inflorescence) and partly by the translocation of stored reserves. (Blum, 1998). When transient photosynthesis is limited by the water stress during grain filling, stem reserve mobilization assumes a greater relative and absolute role in grain filling. Therefore genotypes which had higher harvest index indicated they had more storage of assimilates and better grain filling and thus are desirable in a water limited environment.

4.1.10 One thousand kernel weight

The analyses of this trait in various environments are presented in Table 2. The combined analysis of variance across environments is presented in Table 6. The results show that on a seasonal basis, one thousand kernel weight was significantly different ($p < 0.01$) among genotypes in the three environments. The across location analysis yielded a highly differential response of this trait to variety, location as well

as location by variety interaction (Table 6). The location by variety interaction indicates the inconsistency of genotype performance with respect to their kernel weight across the three environments The variability of this trait in different locations was less than 10 %.

During the first season in Katumani kernel weight ranged from 28.79 to 40.48 g while the second season's kernel weight was ranging from 24.06 to 35.70 g. A range of 28.40 to 37.91 g was observed in Elementaita. The comparisons of means across locations, shows that the second season in Katumani, had the lowest mean kernel weight and were significantly different from the other two sites (Table 9).

When all the sites are combined mean kernel weights, ranged from 27.35 g to 37.91 g with a grand mean of 30.86 g. When varieties were compared with check cultivars, it is observed that during the first season in Katumani, seven genotypes yielded heavier kernels than Ngamia. Duma had very low kernel weight (28.35 g). Duma and Ngamia were not significantly different from entry number 1 which had the lowest kernel weight. Entry number 9 had the heaviest grains and was statistically similar with entries number 8,18 and 11 (Table 3). Entry number 9 also had the highest yield (Table 8), harvest index and above ground plant biomass (Table 3). Similarly, in the second season in Katumani, seven genotypes had heavier grains as than Duma or Ngamia. Entry number 9 was ranked second and was not significantly different from entry number 8 (which had the highest kernel weight) and entry number 18 (Table 4).

In Elementaita, Duma was not significantly different from entry number 18 which had the heaviest grains but Ngamia's kernel weight was significantly different (Table 5). Averaged over locations, the genotypes which had considerably heavy grains were entries number 8, 18 and 9 (Table 7). The grain weights were 37.91 g, 36.58 g and 36.46 g respectively). Four genotypes were having heavier kernels than Duma and Ngamia. Under conditions of water stress, major changes occur during plant growth. Initially roots are the major sinks. When a plant experiences water stress it shows senescence of the leaves but the metabolites are mobilized to the roots. The roots are able to grow more and collect more water or become a source of metabolites if water is again available after a period of stress. Once a plant enters reproductive phase, it mobilizes metabolites to the developing grain/seeds. The process is hastened if the plant experience water stress. Blum *et al.* (1988) observed that a large sink (number of kernels per ear of wheat) in itself promotes stem reserve mobilization to the ear. The size of the sinks influences the senescence of the leaves (Blum, 1996). The larger the sink the faster the senescence and hence greater susceptibility to drought. A non-senescence cultivar may tolerate drought because of sustained source of current assimilates on one hand and stem utilization on the other. If environmental conditions become favourable during grain filling period, the crops that had experienced water stress early in the season thus realizing reduced number of tillers and/or lower number of flowers fertilized can compensate by producing heavy grains. Component compensation was evident in this study. For example, it is observed that during the second season in Katumani the entry, numbers 5,10,13 and

19 had low kernel weights but they compensated by having more grains per head. On the other hand, entries number 1,3,12 and 18 had few grains per head but compensated by having higher kernel weights. In Elementaita entries number 8,9,18 and Duma that had low number of grains per head compensated by having higher grain weights. Combined over locations entries number 3,11,18 had few grains per head but their weights were high. Similar component compensation have been reported by various authors (El Hafid *et al.*, 1998 a; Blum, 1996; Siddique *et al.*, 1990). The expression of higher kernel weights shows that certain genotypes can remain greener and produce better-filled grains than others. Variance of one thousand-kernel weight is genetically controlled trait. Hadjichristodolou (1988) tested five barley varieties and observed significant difference for grain weight among varieties.

In dry land crops, transpiration is linearly related to leaf area up to a leaf area index of 3 (Smith, 1988). It follows that water use is directly related to leaf area throughout much of the crop's life so that a reduced rate of leaf area development should conserve water for grain filling. This means that in the period just before anthesis, when kernel number is very sensitive to drought, a better water status may reduce any catastrophic effect on kernel number if drought is severe. Current assimilation, which is a source of carbon for grain filling, depends on the viable light intercepting green surface of the plant after anthesis. Environmental conditions that decrease current assimilation during grain filling causes a greater demand of stem reserves for grain filling (Blum, 1998). Kiniry (1993) observed that when wheat

plants are shaded during grain filling up to 0.93g of grain was produced per gram of assimilates exported from the stem. Natural senescence and the effect of various stresses reduce the viable light intercepting green surfaces thus diminishing the source of carbon from current assimilates. At the same time, the demand for the growing kernel increases in addition to the demand due to maintenance and respiratory life biomass. If the stem reserve had not been fully accumulated the result is kernel shriveling, reduced test weight and yield loss.

4.2. GRAIN YIELD

Yield is an important character, which is influenced by many genes and environmental factors. This necessitated testing of genotypes across locations and seasons. The yields and their mean separation of 20 bread wheat genotypes tested in three sites are presented in Table 8. In general, the second season in Katumani had the highest site mean (670.4 kg/ha) as compared to Elementaita (485.5 kg/ha) and the first season in Katumani with mean yield of 394.6 kg/ha. Mean grain yield from individual sites differed significantly from each other (Table 9). During the first season in Katumani the yields ranged from 266.3 kg/ha to 574.9 kg/ha. In the second season the yields ranged from 364.7 kg/ha to 1067.0 kg/ha. Elementaita had the highest variation (c.v. =27.62 %) with yields ranging from 312.9 to 776.8 kg /ha as shown in Table 3. The overall means of all seasons combined show that the mean yields ranged from 376.0 kg/ha to 729 kg/ha with an average of 515.1 kg/ha. The high yield realized in the second season in Katumani was attributed to the high

rainfall received during this season. Rainfall data during the growing season are presented in appendix E.

The analysis of variance showed that genotype performance was significantly different over environments with Elementaita showing significance at five percent level of probability. In the combined analysis of variance there was a high and significant variation in yield due to variety , location as well as location by variety interaction as shown in Table 6.

During the first growing season in Katumani, seven out of eighteen new lines out yielded Duma with Ngamia being ranked three (Table 8). Nevertheless, the yield of Ngamia (443.58 kg/ha) was not significantly different from the yield of entry number 9 which recorded the highest yield (574.86 kg/ha). On the other hand, the yield of Duma (413.19 kg/ha) was significantly different (Table 4) from entry number 9 but had statistically the same yield with entry number 4 which realized the lowest yield (266.33 kg/ha). In the second growing season in Katumani three genotypes had higher but statistically similar yield to that of Ngamia while Duma was ranked number nine (Table 8). Entry number nine was the highest yielding genotype in both seasons as shown in Table 8. Elementaita showed four and five genotypes out yielding Ngamia and Duma respectively. The four genotypes were significantly different from Ngamia in their yield (Table 8). Duma on the other hand was not significantly different from entry number 12, which had the lowest yield. When mean yields are combined over locations, and separated, four genotypes had a significantly higher yield than Ngamia with seven genotypes out yielding Duma (Table 8). Entry number

4 which realized the lowest mean yield (375.96 kg/ha) was significantly different from all the other genotypes while entry number eighteen that had the highest yield (728.95 kg/ha) was statistically similar with three other entries (Table 8).

A cultivar might be selected for drought resistance because it maintains high water potential when exposed to extremely low soil water. The relationship of soil water potential to plant water potential is a trait that may or may not contribute to drought resistance. The definition of drought resistance must be linked to survivability. In wheat, the ultimate measure of survivability is production of viable seed. Conveniently for agriculturist, the production of viable seed is synonymous with yield. Indexing yield to some quantifiable measure of stress severity therefore, is the only means of quantitatively evaluating relative drought resistance in a large collection of cultivars. Drought tolerance can then be determined by determining the crops actual yield in the field as a function of some quantifiable index of stress severity.

In adequate availability of water and poor distribution has a profound effect on various plant processes. Growth processes such as the period between germination to spike initiation or spike emergence to grain development have different time scales depending on water deficits or drought. Drought induces changes in leaf water potential, turgor pressure, stomatal resistance, cell growth, accumulation of proline or betaine, degradation of proteins and polysaccharides, leaf expansion, shoot and root growth (Sinha, 1988). Depending on which stage the drought sets in, the above processes will determine the expression of yield

components which will in turn influence the final grain yield. Shalembi and Wright (1992) observed that grain yield is a function of kernel weight, number of spikes per metre row, number of kernels / spike and to a lesser extend test weight. Grain yield under drought is a cumulative effect of various processes over a period of days and months. Plant response to drought varies at different stages of plant growth. Genotypes that are identified as drought resistant at seedling stage do not necessarily exhibit resistance during the later stages of growth particularly the reproductive phase. During the time when the crop is intercepting most of the radiation, an increase in the water use of the crop will be commensurate with the increased dry matter yield. This will generally be associated with increased grain yield. Kobata *et al.* (1992) reported that grain yield of wheat under water stress and low humidity was reduced by 33 % relative to the high humidity mainly as a result of reduction in grain size (Kernel weight).

Growth results in accumulation of dry matter. Any amounts of growth or dry matter production will not help in producing grain yield unless yield components differentiate and develop appropriately. Therefore, reduction in grain yield per plant under drought is due to reduction in yield components. For example, Giunt *et al.* (1993) observed that severe water stress from seedling to maturity reduced all yield components. However, the reduction in yield components was variable. The authors observed that the number of fertile ears per unit area was reduced by 60% while grain number per ear was reduced by 48%. Entry number 1,4, 6 and 10 for example had very low yields. Looking at the variables (yield components) it is observed that they

had very low yield component values particularly the number of spikelets per spike, above ground biomass, harvest index and kernel weight. Their respective number of tillers per plant and number of grains per head however were high indicating that all components were not affected the same way. It is further observed that those entries which gave high yields for example entry number 7, 8, 9 and 18 had a better performance in their yield components such as above ground biomass, kernel weight, plant height and harvest index.

The processes of yield realization actually start after ear or spike initiation (Sinha, 1988). At this stage, the current assimilates or photosynthates and mobilization of the previous accumulated nitrogen are important for grain development. When grains develop, they trigger senescence of the flag leaf resulting in the mobilization of protein nitrogen to the flag leaf. The effect of drought stress on yield and its components is mediated by source to sink interaction possibly involving regulation of hormones and carbon pool. Simane *et al.* (1993) observed that water stress during the reproductive stages from anthesis to maturity resulted in grain yield reduction of 88% (58% and 30% at anthesis and grain filling respectively). Therefore, it appears that anthesis is more critical in determining the final crop yield if stress occurs at this stage.

Table 8 : Mean yields of twenty bread wheat genotypes tested in three environments during the 1998/1999 growing season in Kenya

Entry No.	Katumani Season one	Katumani Season two	Elementaita	Mean
1	285.57 d	644.88 bcde	318.74 d	416.40 g
2	269.51 d	615.96 bcde	473.25 bcd	452.91 g
3	448.02 abc	510.90 de	501.23 bcd	486.71 defg
4	280.64 d	364.66 e	482.59 bcd	375.96 h
5	351.07 cd	729.10 bcd	381.49 cd	487.22 defg
6	380.07 bcd	365.72 e	447.02 bcd	397.60 g
7	459.33 abc	820.95 abc	616.04 ab	632.11 abc
8	470.05 abc	1030.55 a	609.55 ab	703.38 ab
9	574.86 a	1067.01 a	471.78 bcd	704.56 ab
10	357.88 bcd	455.28 de	414.31 bcd	409.06 g
11	508.18 ab	643.55 bcde	369.29 cd	507.00 cdef
12	470.80 abc	566.32 cde	312.92 d	450.01 fg
13	463.86 abc	722.40 bcd	511.56 bcd	565.94 cdef
14	266.33 d	397.74 e	614.72 ab	426.26 g
15	322.47 cd	519.55 de	481.99 bcd	441.34 fg
16	372.85 bcd	623.82 bcde	377.74 cd	458.14 efg
17	367.64 bcd	861.05 ab	523.08 bcd	583.92 bcde
18	386.70 bcd	1023.35 a	776.80 a	728.95 a
Duma	413.19 bcd	603.81 cde	484.65bcd	500.55 defg
Ngamia.	443.58 abc	894.52 ab	540.36bd	624.47 bcd
Mean	**394.62**	**670.40**	**485.46**	**515.10**
SE	17.49	31.94	24.77	17.69
Lsd 0.05	156.50	285.84	221.62	127.89
C.V	23.99	25.79	27.62	32.19

* Means having the same letter within a column are not significantly different at 5% level of lsd.

Table 9: Separation of yields and yield components of 20 bread wheat genotypes by location.

Environment	Katumani		Elementaita	Mean
	1st season	2nd season		
Yield (kg/ha)	394.62 c	670.40a	485.46b	515.10
Tillers / plant	3.21 a	3.17a	2.81b	3.06
Spikelets / spike	12.39 b	13.65a	12.64b	12.90
Plant height (cm)	45.17 b	59.13a	42.32c	48.87
Ear length (cm)	7.25 b	8.05a	7.28b	7.52
Above ground biomass (t/ha)	1.41 c	3.11a	2.31b	2.27
Kernel weight (g)	32.17 a	28.13b	32.18a	30.86
Harvest index	0.275 a	0.218b	0.223b	0.239
Grain per head	-	27.78b	30.34a	29.08
Days to maturity (from planting)	95.78a	92.70b	-	94.24

Means having the same letter within a row are not significantly different.

4.3. CORRELATION ANALYSIS:

4.3.1 Relationship among yield components

The correlation matrix of the wheat parameters measured during the first season in Katumani is presented in Table 10. The results indicate that tillers per plant correlated significantly only with harvest index. It had positive but non significant correlation with all the variables measured except days to maturity. During the second season tillers per plant had a non significant correlation with all the variables measured (Table 11). Similar results were reported by Schonfield *et al.*, (1988). Tillers per plant measured in Elementaita were only correlated but negatively with grains per head (Table 12). Combined correlation matrix (Table 13) shows that tillers per plant had very weak association with plant height, ear length and harvest index. The above results show that the early part of the vegetative period was conducive to growth resulting in tall plants with more tillers per plant. Genotype with high harvest indices indicated that they were able to convert the high dry matter as reflected by their high number of tillers and tall heights into grain yield. These lines possibly have better utilization of stored assimilates.

During the first season in Katumani, spikelets per spike were correlated with plant height, ear length, above ground biomass and harvest index (Table 10). In the second season, spikelets per spike was correlated with ear length and days to head but negatively correlated with kernel weight. Similar results were reported by Simane *et al.* (1993). This means that as spikes produce more florets some of these florets do not fill

due to water stress. As a result, there is flower abortion and the grains that will survive and filled will be shriveled thus recording low kernel weights. In Elementaita spikelets per spike were highly correlated with ear length and number of grains per head (Table 12). When means of spikelets per spike among genotypes are combined and correlated, positive correlations between spikelets per spike and plant height, ear length, as well as days to head were obtained. On the other hand, kernel weight were negatively correlation with spikelets per spike ($r = -0.318^*$) (Table 13).

Plant height was highly correlated with most of the variables measured except tillers per plant in Katumani during the first season. Days to maturity however, was negatively correlated with plant height ($r = -0.440^{**}$) in the same environment (Table 10). In the second season, there was a high correlation of plant height with above ground biomass ($r = 0.386^{**}$). Mohamed (1992) also reported a positive correlation of plant height with above ground biomass. A significant negative correlation was observed between plant height and the number of days from planting to 50% heading ($r = -0.539^{**}$) in Katumani during the second season (Table 11). This suggests that taller plants took less time to head as compared to short cultivars. Plant height also was correlated with above ground biomass and kernel weight in Elementaita (Table 12). This indicates that taller plants had more above ground biomass leading to higher grain yield as reflected in the positive correlation ($r = 0.310^*$) of plant height with yield. This is possibly due to a better light interception because of their height. This will result in a higher photosynthetic rate, which will support higher kernel weight. Combined correlation analysis showed that plant height was highly correlated with ear length ($r =$

0.518**), above ground biomass (r = 0.563**) but negatively correlated (r = -0.544**) with the length of time from planting to the time when most plants within a plot reached 50 % physiological maturity (Table 13).This indicates that taller plants had longer ears and higher above ground biomass but took less time to mature. For example, entries number 3, 7, 8, 9, 18, Duma and Ngamia were tall varieties. In addition, they had long ears, higher above ground biomass and matured earlier (Table 7).

During the second season in Katumani, the number of days plants took to head when correlated with other variables showed a high and positive correlation with the number of days from planting to maturity and ear length. Correlated with spikelets per spike a significant positive correlation at $p < 0.05$ was observed. Plant height, kernel weight and above ground biomass however showed a significant negative correlation with the number of days to head. (Table 11). Maturity time on the other hand was highly correlated with ear length but negatively associated with above ground biomass in the same environment. In Katumani during the first season the number of days plants took to mature was negatively correlated with above ground plant biomass, plant height, harvest index and kernel weight (Table 10). Blum et al. (1992) reported a negative correlation between the number of days to maturity and harvest index. Ear length showed a negative but non-significant correlation with days to maturity (Table 10). Combined correlation analysis between days to maturity and other yield components indicated that, the number of days plants took to mature was significantly

correlated with days to heading. Plant height and above ground plant biomass showed a significantly negative correlation with the number of days to maturity (Table 13).

The correlation of ear length with other components of yield indicated that it was highly correlated with spikelets per spike, plant height and harvest index in Katumani during the first season. Kernel weight showed significance at $p < 0.05$ (Table 10). In the second season, at the same site ear length was highly correlated with spikelets per spike, days to maturity and days to head. Variables such as above ground plant biomass, harvest index, kernel weight and grain per head, had a negative but non significant correlation with ear length as shown in Table 11. The longer the spike the more the spikelets. This means that there are many sinks in the plant relative to availability of assimilates. The plant will develop more florets that might never bear seeds. Under water stress, flower abortion and male sterility occurs leading to few number of flower forming grains. The grains so formed will not have sufficient assimilates and therefore will be shriveled and record low kernel weights. The correlation between ear length and number of grains per head in Elementaita was also significant (Table 12). Ashira, (1998) while working on rice cultivars reported that panicle length was highly and positively correlated with number of panicles/ plant, number of filled grains per panicle and 1000-kernel weight. Combined across locations, the correlation analysis between pairs of characters (Table 13) showed that ear length was positively associated with spikelets per spike, plant height, above ground biomass and days to heading.

The plants above ground biomass among the genotypes tested indicated a high correlation with harvest index and kernel weights in both seasons at Katumani. (Table 11). A significant negative correlation coefficient was recorded between above ground biomass and harvest index in Elementaita (Table12) and for combined analysis (Table 13). The correlation analysis for harvest index with other traits showed that it was highly correlated with kernel weight in all the sites except Elementaita (Tables 10 and 11). Shalembi and Wright (1992) reported a positive correlation between harvest index and Kernel weight while working with 20 wheat genotypes in Arusha region of Tanzania. A significant correlation between harvest index and kernel weight (r =0.346**) was also recorded when means across seasons were combined (Table 13).

4.3.2 Correlation of yield with yield components

During the first season in Katumani, grain yield was highly correlated with spikelets per spike, plant height, above ground biomass, harvest index, and kernel weight (Table 10). It was however negatively correlated (r = -0.454) with the number of days to maturity. Tillers per plant showed a positive but non significant correlation with yield. Kinyua (1991) observed that under variable environments, yield was highly correlated with tillers per plant, ear length and spikelets per spike. Bhutta and Chowdhry (1999) also observed high correlation between yield per plant and number of tillers per plant. In the second season the correlation of yield and other variables was positive and significant for plant height (r =0.479), above ground biomass (r = 0.767), harvest index (r= 0.561) and kernel weight (r =0.587). The high yield of some genotypes such as entry number 3, 9,17 and 18 (Table 4) is attributed to their ability to

maximize kernel production and better partitioning of assimilates to grain so as to realize higher harvest index given the high above ground biomass. The above entries recorded the highest kernel weight as shown in Table 3. The correlation between grain yield and kernel weight under drought was also recorded by Malik and Wright (1998) while testing six drought tolerant and six drought susceptible wheat genotypes having the same phenology. Kinyua and Ayiecho (1992) observed a positive correlation between grain yield and plant height. Similarly, Jaradat (1992) noted that drought resistance was highly correlated with plant height, ear length and higher kernel weight. A significant negative correlation of grain yield with days to Maturity (r = - 0.393) and days to head (r = - 0.544) was recorded in this study (Table 11). Tillers per plant showed a positive (0.216) but non-significant correlation, while spikelets per spike showed a negative non-significant correlation (r = - 0.254) with yield. Simane *et al.* (1993) reported that grains per spike and spikes per metre square were highest under non stress conditions but as the number of spikes/m^2 increased it resulted in fewer grains per spike and low kernel weight.

The correlation analysis for yield and yield components in Elemerntaita is presented in Table 12. Grain yield was significantly correlated with above ground biomass and kernel weight. Similar results were reported by Rajaram *et al.* (1996) between grain yield and biomass. Plant height showed a positive significant correlation with yield at $p < 0.05$.

When mean yields are correlated with the means of other variables, the results indicated that, the grain yield was highly associated with plant height (r =0.565**),

Kernel weight (r = 0.727**) and above ground biomass (r =0.795) (Table 13). The number of tillers per plant, the spikelets per spike and harvest index had positive but non significant correlation with yield. Simane *et al.* (1998) observed that the direct effect of number of spikes per metre on grain yield was positive and significant. Shalembi and Wright (1992) reported a positive but non-significant correlation coefficient between kernel weight and grain yield. Hucl and Baker (1989) also reported the correlation of yield with tillers per plant, spikelets per head and plant height. On the other hand however, days to maturity and days to head showed a negative but highly significant correlation with grain yield. This indicates that when growing period is long plants are subjected to a lot of stress in the field thus will not realize optimum yields. Simane *et al.* (1998) reported negative correlation between the length of vegetative period and grain yield. The authors observed that when vegetative period is long, there is reduced grain filling. They also observed a negative association of long vegetative periods with drought resistance indicating that late maturing varieties are not drought tolerant. The number of grains per head in all the sites and when means are combined recorded a positive but non-significant correlation with grain yield (Table 11, 12 and 13). This contradicts what Shanahan *et al.* (1985) found out. The author reported a significant positive correlation between the number of kernels per metre square and yield, indicating that kernel number is a yield determinant. Shalembi and Wright (1992) also observed a significant correlation between the number of kernels per spike and grain yield.

Yield is formed by creation of a sink and its subsequent filling by the source. Drought stress affects yield by depressing both the sink and the source depending on the timing and severity of the stress with respect to plant phenology. The high correlation between yield and height (r = 0.565 **) as shown in Table 13 indicates that those genotypes which had longer stems were having more sinks for storage of assimilates. These assimilates possibly were remobilised for grain. Taller cultivars have better light interception for carbon dioxide fixation. This improves the photosynthetic capacity of genotypes. Austin (1988) reported that early drought reduced the yield of semi dwarf lines by 29% and talls by 26 % and late drought reduced the yields by 10 % and 7% respectively. Therefore, whichever type of drought, tall plants have a better advantage than dwarf plants under conditions of low water status. The negative association of plant height with days to maturity as well as days to heading shows that short plants matured earlier than tall plants. Daniels and Al cock (1982) observed that in barley under drought stress, contribution of stem reserve to grain yield was greater in tall than in short cultivars. Taller cultivars have a greater capacity to support grain filling from stem reserves because of their greater storage. There was a high and significant correlation (0.563) between plant height and above ground biomass (Table 13). Mohamed (1992) also reported similar results.

Drought during grain filling often involve not only water but also heat stress, which reduces duration of grain filling. There is normally an increase in the rate of dry matter accumulation under high temperatures but it is not sufficient to compensate for the decrease in duration of grain filling. Although tall varieties can have better capacity

to support grain filling, they could also support greater biomass. This can lead to negative association between plant height and harvest index as well as biomass and harvest index as observed in this experiment (Table 13). Entz and Fowler (1990) found out that semi dwarf cultivars are more productive under favourable water conditions but more susceptible to drought and high temperature stress.

The negative correlation between yield and days to heading and days to maturity indicates that when the grain filling duration is short it will allow avoidance of terminal stress. Longer duration on the other hand may allow greater utilization of stem reserves for grain filling under drought. Hadjischristodolou (1988) observed that if drought occurs late in the season relatively early lines produce high yields whereas relatively late maturity lines gave high yields if precipitation was adequate during the late stages of plant development.

Table 10: Correlation matrix of yield and yield components measured during the first season in Katumani in 1998/1999 growing season

	Yield (kg/ha)	Tillers /plant	Spikelets /spike	Days to maturity	Plant height(cm)	Ear Length (cm)	AGBM (t/ha)	Harvest Index
Tillers /plant	0.107							
Spikelets /spike	0.512**	0.117						
Days to Maturity	-0.454**	-0.066	-0.173					
Plant Height	0.430**	0.026	0.396**	-0.440**				
Ear length	0.123	0.124	0.438**	-0.178	0.499**			
AGBM	0.951**	0.109	0.496**	-0.436**	0.378**	0.213		
Harvest Index	0.854**	0.336*	0.459**	-0.401**	0.429**	0.357**	0.674**	
Kernel Weight	0.234*	0.069	0.182	-0.354**	0.466**	0.290*	0.272*	0.333**

Key * ** Indicates significance at $p < 0.05$ and $p < 0.01$ respectively. AGDM =Above Ground Plant Biomass.

Table 11: Correlation matrix of yield and yield components measured during the second season in Katumani in 1998/1999 growing season.

	Yield (Kg/ha)	Tillers /plant	Spikelets /spike	Days to maturity	Plant height (cm)	Ear length (cm)	AGBM (t/ha)	Harvest index	Kernel Weight (g)	Grains /head
Tillers/ plant	0.216									
Spikelets /spike	-0.254	0.120								
Days to Maturity	-0.393**	0.100	0.193							
Plant Height	0.479**	0.181	-0.114	-0.374**						
Ear length	-0.113	0.126	0.489**	0.332**	0.185					
Above ground biomass	0.767**	0.031	-0.123	-0.397**	0.386**	-0.120				
Harvest Index	0.561**	0.149	-0.104	-0.078	0.250	-0.034	-0.024			
Kernel Weight	0.587**	0.136	-0.306*	-0.241	0.255	-0.057	0.324*	0.444**		
Grains /head	0.181	0.128	-0.232	-0.018	0.215	-0.152	0.173	0.116	0.196	
Days to Head	-0.544**	0.011	0.315*	0.622**	-0.539**	0.370**	-0.282*	-0.460**	-0.493**	-0.105

Key * ** indicates significance at $p< 0.05$ and $p< 0.01$ respectively. AGBM =Above ground biomass.

Table 12: Correlation matrix of yield and yield components measured in Elementaita during the 1999 growing season

	Yield (Kg/Ha)	Tillers /plant	Spikelets /spike	Plant height (cm)	Ear length (cm)	AGBM (t/ha)	Harvest index	Kernel weight (g)
Tillers/ plant	-0.010							
Spikelets/spike	-0.159	-0.145						
Plant height	0.310 *	-0.082	-0.215					
Ear length	0.104	-0.014	0.502 **	-0.038				
AGBM	0.686 **	-0.035	-0.101	0.426 **	-0.045			
Harvest index	0.140	0.093	-0.082	-0.218	-0.099	-0.563**		
Kernel weight	0.339 **	-0.168	-0.237	0.345 **	0.101	0.158	0.143	
Grains/head	0.052	-0.280*	0.610**	0.003	0.322*	0.213	-0.259*	-0.169

Key * ** indicates significance at $p < 0.05$ and $p < 0.01$ respectively. AGBM =Above ground biomass.

Table 13. Combined Correlation matrix of 20 genotypes for 10 agronomic traits measured during the 1998/1999 growing season

	Yield (kg/ha)	Tillers / plant	Spikelets /spike	Days to maturity	Plant height(cm)	Ear Length (cm)	AGBM (t/ha)	Harvest index	Kernel weight(g)	Grains / head
Tillers/ plant	0.166									
Spikelets /spike	-0.180	0.123								
Days to maturity	-0.480 **	-0.153	0.192							
Plant Height	0.565 **	0.190	0.317 *	-0.544 **						
Ear Length	0.013	0.177	0.571 **	-0.207	0.518**					
AGBM	0.795 **	0.025	0.224	-0.481 **	0.563**	0.271*				
Harvest Index	0.704**	0.204	-0.091	-0.597**	-0.098	-0.109	-0.420**			
Kernel Weight	0.727**	-0.022	-0.318 *	-0.078	-0.174	-0.134	-0.102	0.346*		
Grains per Head	0.052	-0.102	0.122	-0.018	-0.089	-0.037	0.105	-0.065	0.115	
Days to head	-0.544 **	0.011	0.315*	0.622 **	-0.539**	0.370**	-0.282*	-0.460**	-0.493**	-0.105

Key * ** indicates significance at $p<0.05$ and $p<0.01$ respectively. AGBM =Above ground biomass.

Growth duration determines water requirements and the probability of exposure to stress both of which decrease in early heading genotypes. Genotypes that matured early indicates that they were either having efficient use of moisture or escaped terminal drought. As water supply is discontinued due to drought, plant water relations undergo three main progressive stages of development. The first stage is where the transpiration and assimilation proceed as in fully irrigated plants until moisture is reduced to a level were water uptake does not meet evaporative demand. At this stage, plants meet transpiration demand by reducing leaf water potential, which might cause leaf tissue structural or functional impairment. The second stage is when transpiration and assimilation are reduced below the potential level. The final stage is when stomata are fully closed and water loss is non-stomatal.

Under favourable condition, longer growth duration is associated with greater biomass but under stress, late heading genotypes show reduced harvest index compared with early heading genotypes. This was indicated by a negative and significant correlation ($r = -0.460$) observed in Katumani during the second season between days to heading and harvest index (Table 11). Blum *et al.* (1992) also observed that late flowering genotypes of cereals have lower harvest indices than early flowering genotypes. When the length of growing season is similar for genotypes, variability in yield among genotypes in dry land areas is attributed to their variation in harvest index. Similar results were reported in sunflower by Fereres *et al.* (1986). The high correlation between plant's biomass and yield ($r = 0.795$) was also shown (Table 13). This indicates that growth rather than partitioning to grain was

more important in determining yield potential in these environments. Thus the correlation between harvest index and yield (r = 0.704) was lower than the correlation between biomass and yield (r = 0.795) though both associations were highly significant (Table 19). Simane *et al.* (1998), while analyzing growth and yield components observed that drought tolerant cultivars had a high relative growth rate (RGR) during favourable periods of the growing season and a low RGR during moisture stress. Therefore, if growth can be maintained particularly during drought (moisture stress) by genotypes, it implies that the genotypes possibly have a mechanism for tolerating drought. By extension, genotypes, which maintained growth thus accumulating high biomass leading to high yields, were tolerant to drought.

Plants have large potential for the creation of yield sinks beyond what is realized even under non-stress conditions. For example, wheat produces more florets than will reach maturity or tillers that will not bear heads. The degeneration of tillers has been attributed to lack of carbon under non-stress conditions (Blum, 1996). When a plant experience moisture stress, at any stage when it is still growing particularly during vegetative phase its response is to produces reproductive organs. At the same time, the plant reduces the reproductive demand for carbon by reducing the number of sinks. Therefore, tillers degenerate, flowers drop, pollen dies and ovules abort under stress (Blum, 1996). In Elementaita, it was observed that grain yield was negatively correlated with the number of tillers per plant (Table 18) showing that those plants which had less tillers yielded more because they maintained a positive carbon balance. Also genotypes that produce large number of tillers

accumulate a large biomass and might deplete soil moisture earlier than genotypes with fewer tillers. EL Hafid *et al.* (1998 a) while testing early season drought tolerant genotypes reported that early maturing cultivars exhibit the lowest maximum number of tillers. From this study late maturing varieties had low yield (there was a negative correlation (r =-0.480) between days to maturity and yield). Therefore, low number of tillers will support higher yield. This is because a plant might produce non-productive tillers that will not bear head to maturity. The late developing tillers due to drought compete with the main stem for plant resource without contributing significantly to yield. The production of infertile late tillers may actually decrease yield of other culms. Therefore, a large number of tillers under low moisture regime may not necessarily be desirable because many may become infertile and not contribute to increased yields. However, early emergence of fertile tillers may be an advantage because yield per tiller is directly related to their age (Shanahan *et al.*, 1985)

Genotypes which had long ears also, had higher number of spikelets per head as expected. Some yield components are developmentally correlated such as kernel mass and the number of kernels per inflorescence. Component compensation is an important developmental mechanism for reconstituting yield under or upon recovery from stress. For example, Blum (1996) noted that, it is common to observe an increase in sorghum kernel weight under drought stress due to decrease in kernel number per panicle or an increase in kernel weight in compensation for a decrease in panicle number. From this study, it was observed that genotypes which had short ears

had few spikelets per head ($r = 0.571$) and less number of grains per head. However, they compensated by having high kernel weight. Number of spikelets per spike and kernel weight were significant and negatively correlated ($r = -0.318^*$) (Table 13).

4.4 GENOTYPE BY ENVIRONMENT (G x E) INTERACTION

The combined analysis of variance for yield and other agronomic traits across environments is presented in Table 6. The results indicate that except for ear length, all the other variables showed a significant genotype by environment interaction. Kinyua, (1991) also observed significant G x E interaction among wheat cultivars tested over variable environment. The traits which showed particularly high significance were grain yield, tillers per plant, plant height, days to maturity, above ground biomass, kernel weight and kernels per head. Number of spikelets per spike and harvest index showed significant G x E interaction at $p < 0.05$. This indicates that genotypes reacted differently to different environments. This is also reflected in the changes in relative ranking of genotypes over sites and seasons (Table 14). Changes in relative ranking of varieties over environments as an effect of the environment on wheat performance over multiple locations was also reported by Kinyua (1992). However, in multiple environments genotype by environment interaction increases making it difficult to identify specific performance of individual varieties. Varieties that are needed are those that react less to the environment.

Table 14 : Ranking of genotypes mean yields of the yield trial in three environments during the 1998/99 growing season

Entry no.	Katumani Season one	Katumani Season two	Elementaita	Combined
1	17	9	20	15
2	17	9	5	15
3	3	15	5	9
4	17	18	5	20
5	15	7	17	9
6	9	6	5	15
7	3	1	2	4
8	3	1	2	2
9	1	1	5	2
10	9	15	5	15
11	2	9	17	7
12	3	13	5	13
13	3	7	5	7
14	17	18	2	15
15	15	15	5	13
16	9	9	17	12
17	9	14	5	6
18	9	1	1	1
Duma	9	9	5	9
Ngamia.	3	4	5	5

Genotype with the same number are not significantly different from one another

When yield ranking was considered across sites, entry number 9 was high yielding (ranked first) in Katumani during both seasons but was ranked number five in Elementaita. Likewise entries number 11 and 12 had poor performance in Elementaita but were ranked second and third respectively in Katumani during the first season. During the second season, they were medium yielding varieties (Table 14) being ranked nine and thirteen respectively. Other genotypes showed consistency in their performance across environments. For example, entry number 8 was a fairly high yielder across all environments. Duma also showed similar behaviour and was being ranked nine in two sites and number five in the other site. When means across site were ranked, it is observed that, entry number 11 was number seven but it had shown poor performance in Elementaita indicating that it had variable performance across environments. On the other hand, if mean yields are used, entry number 14 could have been rejected since it was ranked number fifteen whereas it had shown very good performance in Elementaita by being ranked second. The mean yield is not a satisfactory basis for selection of wheat varieties due to variation in stability among genotypes. Rather, recommendation should be based on climatic and physical characteristics of the environment in question. The relative ranking of genotypes in terms of their performance for other agronomic traits was also variable. Traits showed inconsistency across environments suggesting that genotype, environment and their joint effects all affected wheat performance. Therefore, recommendation should be based on actual performance in each particular location or site.

4.5 STABILITY ANALYSIS

The stability analysis from joint regression estimates (Table 15) indicates that above ground biomass, kernel weight, plant height, harvest index, spikelets per spike and ear length for most genotypes were stable as compared to days to maturity, tillers per plant and grains per head which were significantly unstable. Entry number 18 for example showed the highest mean yield indicating that it had biological stability. From the regression coefficient estimates, it was observed that this entry had stable above ground biomass (b = 1.39), kernel weight (b =1.14), plant height (b = 1.12) however, grain yield (b= 2.17**) harvest index (b = 0.29*) and spikelets per spike (b = -0.35*) were unstable for this entry (Table 14). Kinyua and Ayiecho (1992) reported that plant height, above ground biomass and days to maturity were unstable for the genotypes they considered.

Entries, which showed instability in yield, included entries number 6, 8, 9, 14, 17, 18 and Ngamia. Entry number 8, 9 and 18 had high mean yield and most of their yield components were stable. Entry number 11 and 12 showed unstable kernel weight. Among the yield components that were highly correlated with yield, above ground biomass, plant height, kernel weight and harvest indices were stable for most varieties. The number of days to 50 % maturity was correlated to yield but it was highly unstable (Table 15). Geleta *et al.* (1992) reported a stable harvest index for improved bread wheat varieties in nine locations in Ethiopia. Kernel

weight which, was significantly correlated with yield in all the environments was also stable for most genotypes. This means that under unfavourable conditions, those varieties that had high harvest index, kernel weight and matured earlier can possibly give higher yields if conditions are favourable. A farmer will probably be better of if he grows varieties that have yield potential to give good returns in good seasons even if relatively disappointing in bad seasons. The genotypes are well buffered and could adjust their response to the changing environment. Therefore harvest index, kernel weight and days to maturity can be considered as most suitable parameters to be used as selection criteria. However, Kinyua and Kirigwi (1994) observed that yield components such as spikekets per spike, seeds per head, tillers per plant and hundred-kernel weight and ear length were unstable over environments. The above stability analysis measures Type 2 stability where a variety is considered stable if its response to environment is parallel to the average response of all varieties in a test (Eskridge *et al.*, 1991; Lin *et al.*, 1986). This stability is a relative measure, which depends on the varieties in a trial, and thus the stability is restricted to only those varieties being tested. However, this method was used since the set of genotypes were being evaluated relative to the check varieties. Lin *et al.* (1986) while examining nine stability statistics currently in use pointed out that using the variance of yield across sites is sound and simple. However, this measures biological stability, which has a major draw back. Biological stability refers to the production of a constant yield by a genotype whatever the environmental conditions while a genotype is considered to have agronomic

stability if its yield varies in proportion to the productivity of the environment. Biological stability is useful in the absence of genotype by environment interaction but from the analysis of variance Gx E interaction was highly significant indicating that agronomic stability is ideal for identifying genotype performance across environments. Biological stability can be changed into an agronomic measure if relative yield is used as proposed by Yau and Hamblin (1994).

The yield of a genotype at any site can be expressed relative to the mean yield of that site. At each site, entries having relative yield values < 100 yield less than the site average. Entries having relative yield values > 100 yield more. The mean relative yield is the average of individual relative yield across sites. Lines having low variance and high mean relative yield are desirable. Lines with above average mean relative yield and large variance posses specific adaptation and should be selected for specific environments (Yau and Hamblin, 1994).

From agronomic point of view, adaptability refers to yield itself. A cultivar is considered well adapted to the region if its yield is high relative to the other cultivars. In contrast, stability refers to variability of yield. A cultivar is considered stable if its variability is low.

Table 15: The slope(b) of the agronomic traits from the Linear regression analysis as indicators of stability.

Entry No	Yield (kg/ha)	Tillers / plant	Spikelets / spike	Ear length	Plant height	AGBM (t/ha)	Kernel weight	Harvest index	Days to maturity	Grains /head
1	1.37	-1.0*	1.22	0.87	0.96	0.85	0.02	0.09	0.22*	0.56
2	1.24	0.33	1.22	0.83	0.84	0.97	0.36	0.50	5.95**	2.62**
3	0.20	0.26	1.37	1.77*	0.76	0.60	1.03	1.66*	0.54	1.41
4	0.17	-0.19*	-1.54*	1.09	0.96	0.72	1.56*	1.06	2.38**	6.47**
5	1.60	0.12	0.77	0.70	0.96	0.01*	0.77	0.05	1.09	0.69
6	-0.11 **	-0.99*	1.65	2.65**	0.55*	0.17*	1.27	0.70	1.46	0.30
7	1.28	-2.89**	0.95	0.77	0.74	1.85*	1.07	1.56	-0.22**	0.55
8	2.07**	0.14	0.88	1.27	1.33	1.26	0.84	0.19	0.11*	-2.99**
9	1.99*	1.93*	0.22	0.53	1.37	1.08	0.94	1.38	-1.08**	-3.49**
10	0.33	1.65	1.20	1.14	1.21	0.61	0.81	1.39	1.41	4.15**
11	0.64	1.79*	1.46	0.66	1.24	0.78	2.09**	2.12*	0.87	2.47**
12	0.50	0.84	0.83	0.62	1.04	0.45	-0.01**	0.90	2.06*	2.00
13	0.97	-0.61*	1.11	0.92	1.08	1.26	1.25	2.02*	1.30	-0.23*
14	0.23*	0.88	2.04*	2.11*	0.51*	1.07	1.91*	1.91	1.73	3.14**
15	0.64	-0.65*	1.49	1.11	1.23	0.59	1.21	-0.29**	2.60*	-0.59*
16	0.97	6.04**	0.92	0.25	0.97	0.89	0.52	0.63	-0.76**	2.42*
17	1.79**	7.43**	2.46**	0.73	0.26**	1.25	1.26	0.43	3.48**	2.93**
18	2.17**	1.28	-0.35*	0.49	1.12	1.39	1.14	0.29*	0.76	1.39
Duma	0.68	2.05*	0.43	0.23*	1.03	0.89	1.21	1.61	-0.11*	-7.70**
Ngamia	1.66*	2.96**	0.34	1.34	1.03	1.24	1.11	0.91	2.16**	4.07**

* ** Indicate traits which are significantly unstable when measured using t test at $p < 0.05$ and $p < 0.01$ levels of probability respectively.
AGBM = Above ground biomass

Table 16 indicates the relative yield of entries in the three environments as well as their mean relative yield. Relative yield removes the drawback associated with the variance of yield across environments as a stability measure and allows easy comprehension of G x E structure. It also gives equal weights to each site when calculating cultivar means and allows easy comparison of different entries tested in different experiments in the same site and year. In addition, relative yield helps identify genotypes having broad and specific adaptation across sites.

From Table 16, it is observed that the largest change in variance between actual yield and relative yield was for entry number 3. It had the lowest variance when actual yield was used indicating that it was biologically stable. When relative yield is used, it had high variance indicating that it was unstable agronomically. Entry number 7 had a high variance (ranked eight) when actual yield is used indicating that it had biological instability but when relative yield is used it had the lowest variance indicating good agronomic stability. Closer examination of the data shows that this entry had above average yield in all the sites asserting the use of agronomic stability in evaluating cultivar performance. Likewise entry number 20 (Ngamia) showed that it was unstable when variance of actual yield was used but when relative yield was used, the variety was stable. This supports the use of relative yield as a measure of stability. Entry number, 8 showed broad stability by having above average yield in all the sites. Relative yield also helps identify genotypes having specific adaptation. For example entry number 9 had a high mean yield (ranked second) but was specifically adapted to Katumani. The entry had above average yield in those two sites. Likewise,

entry number 11 and 12 had below average yield in the other site except Katumani during the first season. These entries were particularly adapted to this environment. In contrast entry number 14, which had very low mean yield (ranked number 15), was specifically adapted to Elementaita.

Confirmatory test was carried out in Lanet research station in Nakuru district during the 1999 growing season. The results indicate that entry number 9 which had consistently higher yield in all the environments was still the highest yielding variety. It was ranked first in this environment as shown in Table 17. The entries that yielded higher than Duma and Ngamia were entries number 8 and 9. These entries had also yielded higher than the check in Katumani during both seasons and in Elementaita. Therefore the two entries are stable since they can give relatively higher yield in several environments. Entries that gave higher yield than the average yield are entries number 3, 8, 9, 14, 18 and 20 indicating that these entries were adapted to this particular environment. From the results of the other environments, entries number 7, 8, 9, 14, 17 and 18 showed wide adaptability. The entries that gave high yields were also short. This confirms the high negative correlation between height and yield. For example entry number 8, 19 and 20 were shorter in height but gave good yields.

Regression analysis of genotypes, stability analysis, genotype by environment interaction and performance under stress per se used in tandem has proved to be a more complete way of describing genotypes stress tolerance than any analysis used alone. The use of relative yield rests solely on the aim of the research. If the aim is to test whether there a significant genotype by environment interaction then there is no

need to use relative yield. If the aim is to select widely or narrowly adapted lines, then the use of relative yield after the routine analysis of variance procedure with actual yields is necessary.

Table 16: Relative yield (% of mean site yield) of 20 bread wheat entries at three sites in Kenya

Entry No	Site one	Site two	Site three	Mean	Standard Deviation of relative yield	Standard Deviation of actual yield
	% of site mean					
1	72	96	66	78	15.9 (11)	198.57 (7)
2	68	92	97	86	15.5 (12)	174.12 (10)
3	114	76	103	98	19.6 (8)	33.86 (20)
4	71	54	99	75	22.7 (6)	101.45 (16)
5	89	109	79	92	15.3 (13)	210.03 (6)
6	96	55	92	81	22.6 (7)	43.39 (19)
7	116	122	127	122	5.5 (20)	181.34 (8)
8	119	154	126	133	18.5 (9)	291.79 (3)
9	146	159	97	134	32.7 (3)	318.1 (2)
10	91	68	85	81	11.9 (15)	49.06 (18)
11	129	96	76	100	26.8 (5)	137.13 (13)
12	119	84	64	89	27.8 (4)	127.97 (14)
13	118	108	105	110	6.8 (19)	137.58 (12)
14	67	59	127	84	37.2 (1)	175.94 (9)
15	82	77	99	86	11.5 (16)	104.64 (15)
16	94	93	78	88	9.0 (17)	143.51 (11)
17	93	128	108	110	17.6 (10)	252.27 (4)
18	98	153	160	137	34 (2)	321.01 (1)
Duma	105	90	100	98	7.6 (18)	96.30 (17)
Ngamia	112	133	111	119	12.4 (14)	237.40 (5)
Mean*	394.62	670.40	485.46	515.10		
C.V*	23.99	25.79	27.62	32.19		
LSD(%)*	12.7	13.6	14.6			

*Mean and Coefficient of Variation (C.V.) as in the actual yield analysis;
LSD % * = LSD x 100/ mean; Numbers in parenthesis indicate the ranking of genotypes in terms of their variance.
Site one, two and three are Katumani during the first and the second season and Elementaita respectively.

Table 17. Yield in kg/ha and plant height of the eighteen entries and two checks tested in Lanet during the 1999 growing season

Entry No	Yield kg/ha	% of site mean	Rank	Plant Height	Rank
1	541.67	75	18	49.00	16
2	552.08	77	17	47.67	18
3	895.83	125	4	53.33	13
4	635.42	88	12	55.00	9
5	375.00	52	20	53.67	12
6	645.83	90	10	64.67	1
7	583.33	81	15	51.00	15
8	1041.67	145	2	55.00	9
9	1156.29	161	1	48.33	17
10	625.00	87	13	62.33	2
11	645.83	90	10	56.33	8
12	604.17	84	14	59.00	5
13	708.33	99	8	57.67	6
14	822.92	115	7	57.00	7
15	666.66	93	9	52.33	14
16	583.33	81	15	45.67	19
17	468.75	65	19	44.33	20
18	843.75	117	6	54.00	11
Duma	864.58	120	5	60.00	3
Ngamia	1104.17	153	3	59.33	4
Mean	718.23	100		54.28	

4.6 SEMI ARID WHEAT SCREENING NURSERY (SAWSN)

Grain yield in the first season in Katumani ranged from 95.65 kg/ha to 1281.00 kg /ha with a mean of 538.67 kg/ha. The standard deviation was 397.25. In the second season the yield ranged from 73 kg/ha to 1943.25 kg/ha with a mean of 774.40 kg/ha. The yields in Elementaita ranged from 55.50 kg/ha to 1918.25 kg/ha. Generally the entries had a higher average yield in Katumani during the second season as compared to the first season in the same location and in Elementaita. Across environments grain yield was correlated with spikelets per spike, plant height, kernel weight and grains per head but negatively correlated with days to heading (Table 18.8). In Katumani during the second season, heading dates varied between 48 days to 66 days with most entries heading around 57 days (Table18.3). The entries that headed earlier had a higher grain yield and were shorter in height. The correlation between days to heading and height among genotypes was negative and significant

(r= -0.425) as shown in Table 18.6. Days to head had a negative and highly significant correlation with yield (r = -0.384), harvest index (r = -0.353) and grains per head (r = -0.239). A negative correlation between number of days to heading and grain yield have been reported (Anon, 1990)

Kernel weight and plant height of all the entries measured was significantly correlated with yield (Table 18.6 and 18.7). Except in Elementaita harvest index also showed a high association with yield. The number of days from planting to the time taken

to reach 50 % physiological maturity varied among the lines tested. The range was between 86 to 98 days and most entries matured around 91 days from planting (Table 18.3). Number of days to maturity was negatively correlated with plant height while ear length showed a positive correlation. In general, traits which were correlated with yield as shown in Table 18.8 were plant height (r = 0.361*) spikelets per spike (r = 0.341*) and kernel weight (r = 0.237*). This indicates that these traits were good predictors of yield and could be used as selection indices. Harvest index was also highly correlated with yield in Katumani (Table 18.5 and 18.6). Similar correlation has been reported by Rajaram *et al.* (1996).

Genotypes reacted differently to different environments. Tables 18.2 to 18.4 provides data summaries for the entries with the highest or the lowest values in each season for various traits recorded. The yield of entries relative to the check are presented in Table 18.1.The results show that the entries which yielded more than the check variety in two environments and scored three and above were 8, 11, 21, 24, 42, 54, 56, 68, 71, 168, 187. The ones that yielded more than Duma in three environments are entry number 7 and 62. Ngamia and Mbuni are the commercial varieties that yielded more than the check. Entries number 7, 8, 11, 24, 28, 34, 35, 56, 62, 65, 68 and 77 had stable yields. These entries yielded more than the average and were ranked among the top twenty-five in two out of the three environments. These genotypes had higher yield possibly due to their capacity to partition assimilates to grain as reflected in their high

harvest indices and kernel weights. Among the genotypes some were early maturing indicating that they either had better water use efficiency early in the season or they escaped drought. Entry number 8 gave higher harvest index and was tall in Katumani during both seasons. It also headed earlier. This is because the genotype could have stored more assimilates in the stems due to its tall height and remobilized these assimilates to the grain during grain filling period. Entry number 24 had higher harvest index being ranked second and fifth in Katumani during the first and second seasons respectively. Entry number 7 was ranked second in harvest index in Katumani during the first season and it headed earlier during the second season. Entry number 11 had higher harvest index in Katumani during both seasons and matured earlier. In Elementaita entry number 56 had the highest kernel weight with entry number 35 being ranked nine. The variable behaviour of genotypes in their yield potential and other yield components suggests that the performance of genotypes was due to their genetic make up as well as the environment and their joint effects. The results from this screening nursery show that among the pool of germplasm tested, some genotypes have a mechanism of drought tolerance and as such should be retained for further observation and tested in more environments.

Table 18.1 Actual yields, yield as % of local check (Duma) and their ranking in the semi arid wheat screening nursery measured in Katumani and Elementaita

Katumani first season				Katumani second season				Elementaita			
Entry no	Yield Kg/ha	% L.C	Rank	Entry no	Yield Kg/ha	% L.C	Rank	Entry no	Yield Kg/ha	%L.C	Rank
24	1281.00	195	1	35	1943.25	166	1	176	1918.25	345	1
137	1240.00	188	2	66	1894.75	162	2	77	1551.75	279	2
7	1215.50	184	3	11	1812.50	155	3	59	1280.50	231	3
131	1178.17	179	4	63	1789.50	153	4	70	1245.00	224	4
18	1131.50	172	5	24	1772.00	151	5	34	1215.75	219	5
130	1121.50	170	6	84	1658.25	141	6	175	1169.75	211	6
65	1079.17	164	7	8	1651.50	141	7	14	1169.25	211	7
71	1062.16	161	8	54	1607.00	137	8	72	1163.75	210	8
77	1049.84	159	9	89	1606.00	137	9	28	1155.75	208	9
170	1048.60	159	10	88	1571.50	134	10	123	1146.75	206	10
62	1015.50	154	11	29	1497.75	128	11	19	1132.25	204	11
13	1012.83	154	12	26	1475.00	126	12	63	1097.00	198	12
129	1011.00	154	13	34	1445.00	123	13	75	1088.75	196	13
180	994.70	151	14	21	1440.00	123	14	35	1035.00	186	14

LC- Local check

Table 18.1 cont'd

	Katumani first season			Katumani second season				Elementaita			
Entry no	Yield Kg/ha	% L.C	Rank	Entry no	Yield Kg/ha	% L.C	Rank	Entry no	Yield Kg/ha	%L.C	Rank
215	976.80	148	15	7	1436.75	123	15	57	995.75	179	15
126	964.83	147	16	187	1371.25	117	16	48	958.25	173	16
11	964.00	146	17	42	1363.50	116	17	117	957.00	172	17
27	957.00	145	18	62	1362.50	116	18	45	954.25	172	18
75	950.17	144	19	28	1360.00	116	19	162	946.25	170	19
51	938.83	143	20	39	1321.75	113	20	15	932.00	168	20
22	916.16	139	21	30	1319.00	113	21	98	929.25	167	21
9	913.50	139	22	56	1286.75	110	22	178	920.00	166	22
68	908.00	138	23	49	1228.00	105	23	68	912.00	164	23
127	898.50	136	24	113	1226.25	105	24	65	909.75	164	24
8	897.00	136	25	122	1221.75	104	25	56	907.25	163	25
Local check	657.00	100		Local check	1172.12	100		Local check	555.42	100	

LC-Local check

Table 18.2. Plant height, harvest index and associated ranks of selected entries in segregating material of the semi arid wheat screening nursery during the 1998/99 growing season in Katumani

Entry no	Plant height	Rank	Entry no	Harvest index	Rank
177	69.0	1	18	0.47	1
165	66.3	2	6	0.45	2
176	64.5	3	7	0.45	2
99	64.4	4	24	0.45	2
100	63.3	5	11	0.44	5
119	62.8	6	27	0.44	5
96	62.5	7	68	0.44	5
175	61.0	8	9	0.42	8
8	60.8	9	14	0.42	8
92	60.1	10	25	0.42	8
193	59.8	11	133	0.42	8
45	59.5	12	146	0.42	8
50	59.5	12	17	0.41	13
102	59.3	14	30	0.41	13
140	59.3	14	39	0.41	13
46	59.0	16	130	0.41	13
41	58.5	17	137	0.41	13
138	58.5	17	139	0.41	13
197	58.5	17	29	0.40	19
106	58.3	20	40	0.40	19
117	58.3	20	84	0.40	19
			129	0.40	19

Table 18.3 Yield components of selected entries of segregating populations of the semi arid wheat screening nursery measured during the second season(1998) in Katumani Kenya

Tallest entries			Entries with the highest H.I			Entries with heaviest grains			Early heading entries			Late heading enties			Early maturing genotypes			Late maturing genotypes		
Entry no	Plant Height	Rank	Entry no	Harvest Index	Rank	Entry no	Kernel Weight	Rank	Entry No	DTH	Rank	Entry no	DTH	Rank	Entry no	DTM	Rank	Entry no	DTM	Rank
120	82.0	1	4	0.46	1	71	44.00	1	200	48	1	108	66	1	185	86	1	161	98	1
119	74.3	2	26	0.39	2	75	41.80	2	189	49	2	54	65	2	100	87	2	131	97	2
102	74.0	3	7	0.38	3	177	41.52	3	10	49	2	58	65	2	189	87	2	154	96	3
8	73.7	4	124	0.36	4	187	41.52	3	9	50	4	59	65	2	194	87	2	174	96	3
99	72.7	5	24	0.35	5	120	41.35	5	42	50	4	5	64	5	42	88	5	20	95	5
140	72.7	5	8	0.33	6	175	40.92	6	75	50	4	46	64	5	63	88	5	65	95	5
149	72.7	5	91	0.33	6	102	40.37	7	147	50	4	60	64	5	73	88	5	101	95	5
175	72.7	5	105	0.33	6	99	40.23	8	6	51	8	74	64	5	75	88	5	102	95	5
97	72.0	9	138	0.33	6	143	40.00	9	7	51	8	123	64	5	80	88	5	105	95	5
35	71.3	10	11	0.32	10	83	39.90	10	8	51	8	154	64	5	81	88	5	108	95	5
194	71.3	10	29	0.32	10	9	38.75	11	11	51	8	115	63	11	82	88	5	199	95	5
34	71	12	20	0.31	12	49	38.71	12	22	51	8	116	63	11	107	88	5	19	94	12
104	70.3	13	88	0.31	12	56	38.57	13	76	51	8	118	63	11	135	88	5	60	94	12
2	70.0	14	132	0.31	12	146	38.57	13	168	51	8	159	63	11	136	88	5	94	94	12
30	70.0	14	140	0.31	12	105	38.54	15	195	51	8				165	88	5	115	94	12
82	70.0	14	66	0.30	16	22	38.43	16							184	88	5	143	94	12
176	70.0	14	157	0.30	16	186	38.22	17							186	88	5			
16	69.7	18	189	0.30	16	26	37.67	18												
23	69.7	18	200	0.30	16	141	37.50	19												

DTH days to heading; DTM- Days to maturity: H.I- harvest index

Table 18.4 Yield components of selected entries of segregating populations of the semi arid wheat screening nursery measured in Elementaita during the (1999) growing season

	Tallest entries		Entries with highest harvest indices			Entries with Heavy Kernels			Entries with more grains/head		
Entry no	Plant height	Rank	Entry no	Harvest index	Rank	Entry no	Kernel weight	rank	Entry no	Grain/head	rank
176	70.0	1	97	0.56	1	56	42.08	1	122	43.2	1
177	68.3	2	28	0.51	2	143	41.92	2	121	39.6	2
72	66.0	3	44	0.51	2	176	41.48	3	134	39.2	3
30	63.7	4	183	0.50	4	175	40.09	4	46	38.0	4
29	63.0	5	79	0.47	5	88	39.74	5	28	36.4	5
175	63.0	5	133	0.46	6	95	39.05	6	137	36.4	5
86	62.0	7	90	0.43	7	67	38.96	7	162	36.0	7
92	61.7	8	189	0.43	7	179	37.80	8	70	34.4	8
71	61.3	9	145	0.42	9	35	37.57	9	81	34.0	9
119	61.3	9	57	0.40	10	86	37.52	10	127	33.8	10
36	61.0	11	129	0.40	10	2	37.42	11	47	33.6	11
18	60.7	12	160	0.40	10	140	37.34	12	128	33.6	11
137	60.0	13	48	0.38	13	37	37.24	13	179	33.6	11
77	59.3	14	67	0.38	13	79	37.18	14	63	33.4	14
27	59.0	15	105	0.38	13	162	37.17	15	197	33.4	14
118	59.0	15	111	0.38	13	59	37.01	16	139	32.8	16
45	58.7	17	15	0.37	17	97	36.99	17	103	32.0	17
37	58.3	18	93	0.37	17	98	36.81	18	133	32.0	17
63	58.3	18	86	0.37	17	21	36.74	19	39	31.6	19
19	58	20	139	0.37	17	82	36.71	20	19	31.2	20

Table 18.5 Correlation matrix for yield and yield components measured in the semi arid wheat screening nursery during the first season (1998/99) in Katumani

	Yield (kg/ha)	Tillers / plant	Ear Length (cm)	Plant height (cm)
Tillers / plant	0.116			
Ear length	0.167	0.135		
Plant height	0.356 *	0.123	0.389**	
Harvest index	0.795 **	0.078	0.135	0.346*

Table 18.6 Correlation matrix for yield and yield components measured in the semi arid wheat screening nursery during the second season (1999) in Katumani

	Yield (kg/ha)	Tillers / plant	Ear length (cm)	Plant Height (cm)	Harvest index	Kernel weight(g)	Spikelets / spike	Grains / head	Days to heading
Tillers/plant	0.290 *								
Ear length	0.011	0.092							
Plant height	0.347 *	0.082	0.299 *						
Harvest index	0.741 **	0.263 *	0.110	0.212					
Kernel weight	0.260 *	0.056	0.119	0.173	0.372 **				
Spikelets /spike	0.173	0.111	0.265 *	0.371 **	0.031	0.075			
Grains /head	0.398 **	0.041	-0.059	0.192	0.374 **	0.222 *	0.047		
Days to head	-0.384 **	-0.092	0.011	-0.425 **	-0.353 *	-0.126	-0.025	-0.239*	
Days to maturity	-0.111	0.067	0.246 *	-0.311 **	-0.052	0.093	0.118	-0.125	0.473 **

* ** indicates significance at $p< 0.01$ and $P< 0.05$ respectively.

Table 18.7 Correlation matrix for yield and yield components measured in the semi arid wheat screening nursery during the second season (1999) in Elementaita

	Yield (kg/ha)	Tillers/ plant	Ear length (cm)	Plant height(cm)	Harvest index	Kernel weight(g)	Spikelets /spike
Tillers /plant	0.244*						
Ear length	0.012	-0.027					
Plant height	0.550**	0.288*	-0.282**				
Harvest index	0.104	-0.053	0.936**	-0.430**			
Kernel weight	0.461**	0.179	0.050	0.446**	-0.048		
Spikelets / spike	0.335*	0.160	0.663**	0.370*	0.185	0.187	
Grain /head	0.263*	0.250*	0.473**	0.318*	0.225*	0.270*	0.596**

* ** indicates significance at $p < 0.01$ and $P < 0.05$ respectively.

Table 18.8 Combined correlation matrix for yield and yield components measured in the semi arid wheat screening nursery during the 1998/99 in Katumani and Elementaita

	Yield kg/ha	Tillers/ plant	Ear length	Plant height	Harvest index	Kernel weight	Spikelets / spike	Grains per head	Days to head
Tillers/plant	0.112								
Ear length	0.080	-0.004							
Plant height	0.361*	0.045	0.073						
Harvest index	-0.029	0.0003	0.806**	-0.265*					
Kernel weight	0.237*	0.352*	0.006	0.081	0.006				
Spikelets /spike	0.341*	-0.006	0.598**	0.535**	-0.112	0.01			
Grains /head	0.264*	0.269*	0.036	0.056	0.359**	0.270*	0.172		
Days to head	-0.384**	-0.092	0.0110	-0.425**	-0.353**	-0.126	-0.025	-0.239*	
Days to Maturity	-0.111	0.067	0.146	-0.311*	-0.052	0.093	0.118	-0.125	0.473**

* ** Indicate significance at $P < 0.01$ and $P < 0.05$ respectively

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATION

5.1 YIELD TRIAL

Drought tolerance is assessed by determining the crop's actual yield in the field as a function of some quantifiable index of stress severity. The components that were closely related to yield were early heading and early maturity, plant height, ear length, above ground biomass, harvest index and kernel weight. Of all these traits above ground biomass and plant height were particularly unstable for most genotypes. In the yield trial entries number 7, 10, 13,15, 18 and Duma had stable yields whereas entries number 1, 9,12, 16 and 17 had unstable yields.

From this study, the following findings are evident. First genotypes reacted differently to different environments. The significant G x E interaction for most traits and differential ranking of performance of genotypes across environments was proof that the environment had an effect on the performance of genotypes. Secondly among the new lines tested, there are those genotypes, which can yield more than Duma and Ngamia. The latter are varieties, which have been recommended for the low potential marginal environments in Kenya. This also indicates that some genotypes are tolerant while others are susceptible to drought. Entries that were notably

low yielding as well as susceptible to drought were entries number 1,2, 4, 6, 10 and 15. Entries number 6 and 15 however appeared to have better capacity to partition assimilates to grain since they realised high harvest indices irrespective of their low grain yield. In addition, they were early maturing varieties. These entries could therefore be used as a source of breeding stock. Entries number 7, 8, 9,11 and 18 yielded more than the check varieties (Duma and Ngamia) in all the environments. In addition, Ngamia yielded more than Duma in all the environments indicating that it had a better adaptation as compared to Duma.

Among the pool of genotypes tested, some genotypes had the capacity to form many sinks such as tillers per plant, spikelets per spike and ear length. This behaviour could have reduced yield under stress because of high demand for assimilates due to water shortage. However these varieties had better sink strength and were able to translate the high sink capacity to yield. Other genotypes were susceptible to drought. The susceptible genotypes created high reproductive demands for the plant but could not translate them into high yields. That is those genotypes had poor capacity for resource capture and mobilisation to give higher yields under stress.

Thirdly varieties have broad as well as specific adaptation. Entries number 7,8, 9, 14,17 and 18 had a wide adaptation. These entries had high yield in most environments relative to other cultivars in the yield trial. In

addition, they bore more sinks for the plant such as tillers per plant, spikelets per spike and ear length. Under unfavourable environment this genotypes could still give high yields. As for specific adaptation entries number 9 and 11 had high yield and were particularly adapted to Katumani. These entries also gave high harvest indices and kernel weight. Entries number 14, 17 and 18 showed promising adaptation to Elementaita. The genotypes also maintained high yield. These genotypes possibly have drought tolerance mechanisms. These entries had component compensation. They had fewer grains per head but were able to translate them into high kernel weights. Also their higher yields than their respective biomass indicate that they would have had low harvest index but its observed that they partitioned more assimilates to grain than to the vegetative matter thus realising high harvest indices.

The selection work conducted in the three environments has helped in identifying agronomically superior genotypes compared to the best existing cultivars for the drier areas. In agreement with the past findings, entries, which headed within 55 days and matured within 92 days proofed to be desirable.

Taking into account all of the agronomic data considered in this study and keeping in mind that improvement of some of the traits can lead to

grain yield improvement as well as better adaptation, the following lines deserve further attention.

- Entry number 7,8,9 and 18 for their high kernel weight, short duration to maturity, high harvest indices with a grain yield of over 630 kg / ha.
- Entries number 6 and 15 which matured earlier and although their yield was low had better capacity to partitioned assimilates to grain thus realising high harvest indices
- Entries number 11 and 12, which appeared to be susceptible to drought in one environment but adapted to another environment. Further tests for these lines are needed to ascertain their niche.
- Entries with average performance in all the environments and showed stability such as entries number 5, 13 and 17 need to be retained for further tests.
- Entries number 7, 8, 9, 11 and 18, which yielded higher than the check varieties.

5. 2 SCREENING NURSERY (SAWSN)

A prerequisite for breeding for overall resistance to drought is the availability of variable resistant genes in locally available and exotic germplasm. The results of the screening nursery study suggest that the genotypes assessed have varying levels of drought tolerance/resistance. Consequently, the following lines were selected for further evaluation. These

lines are entry numbers 7, 8,11, 18, 14, 15, 18, 34, 35, 45, 58, 54, 56, 62, 65, 68, 71, 73, 76, 77, 129, 136, 162, 170, 174, 183, and 187. These genotypes yielded more than the site mean in most of the environments indicating that they had above average performance across locations. This is a positive indication of stability. The entries selected also showed superior yield components such as kernel weight and harvest index. Therefore, these lines need to be retained for further observation possibly in more environments.

Entries number 18, 25, 48, 54, 71, 73, 76, 129, 136, 162, 170, 174 and 183 scored three and above from visual assessment and are potentially higher yielding than the check cultivars recommended for marginal areas. Further evaluation in more environments is required to establish their yield potential and stability. Additionally, the lines could be used as a breeding material or source of germplasm to be crossed with other promising lines for the development of drought tolerant germplasm.

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APPENDIX

Appendix A. Performance of SAWN entries in Katumani during the first season

Entry No.	Tiller/ plant	Ear Lenght	Plant Height	Harvest index
V1	2.5	6.6	48	0.25
V2	1.3	7.6	48.8	0.18
V3	2.0	7	53.8	0.3
V4	2.4	7.3	52.8	0.33
V5	1.8	8.3	55.8	0.28
V6	2.3	6.5	45.5	0.45
V7	2.5	7.5	51.6	0.45
V8	2.8	7.6	60.8	0.38
V9	2.3	7.5	52	0.42
V10	3.1	7.3	49.5	0.43
V11	2.5	8.4	55.3	0.44
V12	3.5	7.5	56.8	0.25
V13	2.6	7	50.3	0.39
V14	3.8	7.8	56.9	0.42
V15	2.3	8.3	57.8	0.17
V16	2.3	7	56.2	0.2
V17	2.8	7	56.5	0.41
V18	3.8	7.8	56.5	0.47
V19	2.3	7.3	56.8	0.33
V20	2	9	51.8	0.29
V21	2.3	8.5	50	0.25
V22	2.8	10	58	0.37
V23	3.8	7.8	55.3	0.35
V24	1.8	9.3	52	0.45
V25	3.5	8.9	55	0.42
V26	1.8	9	52.8	0.28
V27	1.5	8	54.5	0.44
V28	2.0	7.4	48	0.38
V29	1.8	7.5	51.3	0.4
V30	2.5	8.3	54.8	0.41
V31	2.3	6.6	50.7	0.27
V32	1.3	6.6	40.5	0.3
V33	1.8	6.4	40	0.23
V34	1.0	6.1	36	0.22
V35	1.5	7.3	45.5	0.22
V36	2.5	7.4	48.9	0.37
V37	1.5	6.6	42	0.26
V38	1.3	6.5	45.3	0.22
V39	2.3	6.8	48	0.41
V40	2.5	6.9	53.6	0.4
V41	2.8	6.8	58.5	0.33
V42	2.3	7	51	0.31
V43	2.3	6	50.2	0.22
V44	2.8	6.3	54.5	0.35
V45	1.8	7.1	59.5	0.28
V46	2.3	7	59	0.3
V47	2.5	10.3	57.5	0.27
V48	2.5	8.3	55.9	0.32
V49	2	5.9	49.3	0.19
V50	3	7.4	59.5	0.39
V51	2.3	7.1	55	0.36
V52	1.6	6.8	55.5	0.29
V53	4	7	54	0.35
V54	2	7.4	54.3	0.35
V55	2	6.8	50.5	0.39
V56	3	7.3	47.3	0.27
V57	3	7	51.8	0.28
V58	3.4	7	52	0.29
V59	3.2	7	45.3	0.18
V60	2.2	7.8	47.5	0.28
V61	2	6.5	41.3	0.31
V62	2.2	6.3	48	0.38
V63	2.3	7.4	48.31	0.37
V64	4.3	8	52.6	0.38
V65	2.3	7.4	47.3	0.34
V66	3	7	53.5	0.3
V67	3.2	6.8	47.5	0.33
V68	3.2	6.6	50	0.44
V69	2.4	7.6	50	0.31
V70	2.6	8.5	53.8	0.32
V71	2.6	7.5	54	0.35
V72	2	6.8	43	0.28
V73	2.7	7.4	49.8	0.29
V74	2.2	7	50	0.25
V75	4	7.8	52.5	0.36
V76	2	5.8	49.5	0.33
V77	2.2	7.1	56.5	0.39
V78	2.7	6.1	48.5	0.39
V79	1.5	7.6	47.3	0.34
V80	2.8	8	49.3	0.21
V81	2.5	9	52.5	0.36
V82	2.3	7.4	46.5	0.24
V83	3	7.3	49.8	0.34
V84	2.3	7.9	55	0.4
V85	2.1	7.9	46.5	0.34
V86	1.9	6.8	48.8	0.15
V87	3.3	6	54.5	0.12
V88	2.3	6.1	41.5	0.1
V89	2	7.6	51.8	0.22
V90	2.5	6.8	55	0.3
V91	2.8	6.3	53.8	0.27
V92	4.5	7.9	60.1	0.24
V93	3	9.6	52.8	0.23
V94	2.3	5.9	50.4	0.25
V95	2.5	6	52.4	0.24
V96	2.5	6.6	62.5	0.15
V97	2	6.4	52.1	0.32
V98	4.5	7.5	52.8	0.34
V99	3.3	6.8	64.4	0.38
V100	2.5	6.5	63.3	0.34
V101	2.3	7.8	56.5	0.27
V102	3	8.5	59.3	0.21

Entry No	Tillers/ plant	Ear Length	Plant Height	Harvest index
V103	1.8	7.1	53.5	0.3
V104	2.8	7.9	53.3	0.25
V105	2.8	8.7	51.9	0.29
V106	2.3	7.1	58.3	0.25
V107	3.8	6	56.3	0.37
V108	2.8	5.9	38.8	0.35
V109	1.8	5.6	50.8	0.35
V110	1.8	6.9	52.3	0.11
V111	2	6.5	52.5	0.29
V112	1.5	7.1	46.8	0.12
V113	1.5	6.4	57.5	0.29
V114	2.8	8.1	57.8	0.23
V115	3.3	8.1	47	0.26
V116	5.3	7	39.3	0.19
V117	2.3	7.8	58.3	0.27
V118	1.8	6.4	51.3	0.23
V119	2.3	7.5	62.8	0.23
V120	1.8	8.3	53	0.19
V121	2.8	8.4	54	0.26
V122	3.3	6.8	36.5	0.2
V123	2.3	6.1	51.3	0.35
V124	3.5	6.4	50.3	0.29
V125	2	7	53	0.24
V126	2.4	8	54.5	0.39
V127	4.3	7.4	41	0.34
V128	3	7.4	50.5	0.35
V129	3	7	54	0.4
V130	3.3	8.3	55.3	0.41
V131	1.8	6.5	46.3	0.39
V132	2.8	7.8	48.8	0.33
V133	3.3	6.4	37.8	0.42
V134	2.3	6.8	46.3	0.31
V135	3.3	7.5	52	0.28
V136	2	7.9	55.8	0.39
V137	2.3	7.9	55.5	0.41
V138	3	7.6	58.5	0.37
V139	2.5	7	55	0.41
V140	2.5	8.3	59.3	0.32
V141	1	7.5	48.3	0.32
V142	1.3	6.3	47	0.2
V143	1.5	7.4	44.5	0.29
V144	2.8	6.8	46.3	0.32
V145	2	6.9	48.5	0.26
V146	2.3	6.5	44.5	0.42
V147	1.8	5.6	51	0.32
V148	1.5	5.4	41.5	0.2
V149	2.8	7.3	50.5	0.21
V150	2	7.3	49.8	0.33
V151	1.5	7.1	45.8	0.25
V152	1.8	6.9	46.3	0.16
V153	2.8	7.1	46.5	0.06
V154	3.3	7.8	43.4	0.12
V155	2	6.6	54.3	0.27
V156	3.3	7.9	52.5	0.33
V157	3.8	7.4	44	0.2
V158	2.8	7	49.3	0.21
V159	2.8	7.6	52.3	0.23
V160	4	8	50.5	0.17
V161	3.5	8	56.5	0.32
V162	2.3	6.8	51.3	0.27
V163	5.3	6.9	49.8	0.3
V164	4.8	6.3	43.8	0.16
V165	2.5	8.4	66.3	0.25
V166	1.5	6.6	51.5	0.2
V167	3.5	7.3	57.3	0.28
V168	2	8.1	54.5	0.26
V169	2.5	7.8	53.8	0.17
V170	2.3	7	48	0.35
V171	2	5.5	39	0.37
V172	1.3	7.1	43.3	0.34
V173	1.8	6.3	50.5	0.19
V174	2.5	7.6	47	0.33
V175	2.3	7.8	61	0.29
V176	2.8	9	64.5	0.28
V177	2.3	7.9	69	0.27
V178	4.3	9	56.5	0.33
V179	3	8.3	52.8	0.26
V180	3.8	7.3	57.3	0.36
V181	2.8	6.9	56.8	0.31
V182	2	8.1	54.5	0.22
V183	1.3	7	47	0.17
V184	4.3	8	51.8	0.2
V185	1.8	8.3	55.8	0.27
V186	2.3	6.8	54.8	0.28
V187	1.8	7.6	57.5	0.31
V188	2.5	7.3	47.7	0.27
V189	2	8.9	55.4	0.32
V190	2	9.6	56.8	0.33
V191	3.3	5.5	54	0.28
V192	1.5	8	47.3	0.31
V193	3.3	8	59.8	0.28
V194	2.8	6.1	51	0.2
V195	2.8	6.9	49.8	0.26
V196	2	6.5	53	0.19
V197	1.8	7.4	58.5	0.27
V198	2.5	6.3	52	0.1
V199	3.5	7.5	49	0.31
V200	4	7.3	52.3	0.19

Shaded cells are the Duma checks

Appendix B. Performance of SAWN entries in Katumani during the second season

Entry No	Tillers/ Plant	Ear Length	Plant Height	Harvest Index	Kernel Weight	Spikelets /Spike	Grain /Head	Days to Head	Days to Maturity
V1	2.8	7.8	59	0.21	29.16	13	17.8	59	91
V2	2.8	8.5	70	0.23	33.53	13	30.6	54	90
V3	3	7.8	59	0.17	30	12	25.8	56	90
V4	2.2	8.7	62.7	0.46	28.15	13.3	12.5	61	92
V5	2	7.2	56	0.05	30.67	11.7	6.75	64	89
V6	2.6	7.8	61	0.22	29.28	12.3	16.6	51	91
V7	2.3	8.3	65.3	0.38	30.56	14	25	51	90
V8	2.8	9.8	73.7	0.33	34.06	14	34.2	51	91
V9	2.8	8.2	66.7	0.23	38.75	11.3	21	50	93
V10	2.6	7.7	59.7	0.24	24.52	12.3	20.8	49	91
V11	2.4	9.7	67.3	0.32	25.84	15	27.4	51	89
V12	2.2	7.5	62.3	0.19	23.14	10.3	29.5	54	91
V13	2.8	6.7	56	0.18	32.86	12.3	28.05	55	90
V14	1.7	7.8	62.7	0.16	25.2	12	11.8	53	91
V15	2	7.7	56	0.03	21.9	9	7.6	60	91
V16	2.3	9.5	69.7	0.19	22.46	13.3	17.5	53	92
V17	2.3	8	69	0.16	31.35	11.7	36.7	61	91
V18	2.0	7.8	66.3	0.15	35.2	13.3	25.1	62	93
V19	2.7	7.7	60	0.12	32.69	14	21.4	61	94
V20	2.4	8	63	0.31	31.25	13.7	19.2	62	95
V21	2.9	7	67	0.24	28.91	14	18.4	53	91
V22	3.2	10.3	61.7	0.19	38.43	12.7	21.6	51	92
V23	2.7	8	69.7	0.08	25.49	13	16.4	51	90
V24	2.5	8.7	66	0.35	37.03	13.3	26.1	52	91
V25	2.4	7	59	0.17	35.98	13	22.4	53	90
V26	2.7	9.3	69.3	0.39	37.67	13.7	32.6	55	91
V27	2.8	7.8	67	0.26	25.6	12.7	19.6	54	91
V28	2.8	8.3	66	0.27	16.77	12.7	13	54	91
V29	4.0	8.5	66	0.32	33.3	12	17	54	91
V30	3.0	9.2	70	0.21	33.3	13.3	22	55	89
V31	2.7	8.2	61.7	0.15	24.3	14	14	60	90
V32	2.9	7.2	63.3	0.16	30.39	12.7	18.7	53	92
V33	2.3	7.8	67	0.22	33.55	13.7	21.6	55	91
V34	2.4	8	71	0.25	32.5	13.7	19.2	54	93
V35	2.0	8.2	71.3	0.24	30.84	14.7	28.6	54	92
V36	2.0	6.3	50	0.1	23.17	10.7	27.8	62	91
V37	2.7	8	65	0.22	27.43	13.3	32	56	92
V38	2.0	6.8	61.7	0.22	29.67	13.7	23.8	54	92
V39	3.4	7.2	61.3	0.29	30.71	13.7	22.5	54	91
V40	2.8	6.8	59.7	0.14	18.41	12.7	8.8	57	90
V41	2.3	7	63.7	0.12	25.6	12.3	18.1	57	90
V42	3.0	8.7	63	0.24	32.32	12.3	20.3	50	88
V43	3.0	6	66	0.24	22.45	12	30.7	52	90
V44	2.4	5.8	58.3	0.21	19.92	12	24.2	52	90
V45	2.3	6.7	61.3	0.18	36.5	13.7	32	60	93
V46	2.7	7.2	61.7	0.19	36.73	13.7	30	64	89
V47	2.0	8	64.3	0.23	26.57	15.3	13.4	53	91
V48	2.8	7.3	60.7	0.15	33.73	13	30.6	55	89
V49	1.7	5.5	57.3	0.29	38.71	11.7	28	57	91
V50	3.3	7.8	59.3	0.14	24.1	11.7	18.4	58	91

Entry No	Tillers /Plant	Ear Length	Plant Height	Harvest Index	Kernel Weight	Spikelets /Spike	Grain /Head	Days to Heading	Days to Maturity
V51	2.1	7.3	61	0.18	32.13	11.7	26.9	58	90
V52	2.1	6.2	63	0.09	25.3	13	16.7	55	91
V53	2.3	6.8	68	0.18	31.06	12.7	18.8	52	89
V54	2	7.3	67.7	0.28	30.55	14.3	36.2	65	89
V55	2	5.5	56	0.19	32.33	14.3	25.6	60	93
V56	3.6	7.2	56.7	0.26	38.57	11.3	12.6	61	92
V57	3.8	8.3	59.3	0.19	29.69	13.7	11	61	90
V58	3.3	7.7	63.7	0.08	15.63	13	6.4	65	91
V59	3.3	8.3	56	0.12	21.89	13.3	22.5	65	93
V60	2.8	7.8	54.3	0.17	16.71	14	14	64	94
V61	2.3	5.8	53.7	0.27	28.77	12.7	22.8	55	91
V62	2.7	7.5	57.7	0.29	30.91	12.7	11.2	59	93
V63	3.6	8	59.3	0.29	27.02	12	24.2	54	88
V64	2.7	7.5	63	0.18	31.11	13	18	53	92
V65	2.2	8.2	61.3	0.15	24.8	15.7	8	62	95
V66	3.2	6	60.3	0.3	31.75	13	27.4	52	90
V67	2.4	6.3	58.7	0.18	26.37	12.7	36.4	57	92
V68	2.4	9	62.3	0.17	35.63	12.3	20.6	54	93
V69	2.3	9.3	59	0.15	32.27	13.7	26.4	61	92
V70	2.2	9.3	65.3	0.18	31.43	15	13.6	61	92
V71	2.4	8.5	67.7	0.21	44	15.3	18	54	90
V72	3	9.3	67.3	0.14	24	13.3	10	60	89
V73	2.6	7.8	69.7	0.22	26.4	11.7	20	52	88
V74	2.4	8.3	54.7	0.23	37.26	14.7	33.6	64	93
V75	2.5	6.8	68	0.18	41.8	12.3	24.4	50	88
V76	3	7.7	63.7	0.23	35.13	12	25.6	51	91
V77	2	7.7	60.7	0.17	17.33	13.3	40.5	52	91
V78	2	6.7	55.3	0.21	25.37	12.3	26	61	92
V79	2.6	9.3	69	0.2	32.6	13.7	25.4	54	89
V80	1.3	8	65.3	0.09	26	13	18.4	56	88
V81	2	6	67.7	0.06	23.44	15	12.8	57	88
V82	2	8	70	0.17	30.24	15.7	22.5	53	88
V83	2.6	7.2	60.7	0.24	38.9	12.7	11.6	60	92
V84	3.3	8.2	56	0.26	32.1	13.3	24	59	93
V85	3.8	7.8	58	0.1	16.49	12.7	21.5	60	91
V86	2.8	7.5	58.3	0.15	25.14	13	17.7	60	92
V87	2.6	9	63.7	0.14	30.57	15	24.6	57	91
V88	4.3	8.3	62	0.31	35.52	11.6	26.8	56	92
V89	3.8	7.2	64	0.27	37.33	13.3	30.2	56	92
V90	2.2	6.5	66.7	0.2	27.55	12	22	58	90
V91	2.4	7.8	62.3	0.33	27.92	11.3	9.9	58	90
V92	3.3	7.7	65.3	0.18	32.7	16	9.6	57	93
V93	2.8	9.7	67.3	0.21	31.99	16	21.1	54	91
V94	3	7.7	63.3	0.15	36	13.3	20	59	94
V95	2	6.8	53	0.21	27.87	11	25.4	60	92
V96	2.5	7.5	66	0.17	37.1	15	15.2	52	91
V97	2.4	7.5	72	0.18	18.36	14.3	24.4	52	90
V98	2.7	8	64	0.23	32.64	15	12.2	55	92
V99	3.2	7.7	72.7	0.19	40.23	14.3	35.6	54	92
V100	2.3	9	62	0.18	30.84	14.3	16.7	59	87

Entry No	Tillers /Plant	Ear Length	Plant Height	Harvest Index	Kernel Weight	Spikelets /Spike	Grain /Head	Days to Head	Days to Maturity
V101	2.8	11	65.3	0.18	28.9	14.3	18.4	53	95
V102	3.7	10	74	0.29	40.67	14	27	61	95
V103	2.6	9.2	65.7	0.23	25.6	14.7	27.7	52	91
V104	2.5	7.8	70.3	0.2	34.59	14.3	32.8	53	90
V105	2.2	8.7	57.3	0.33	38.54	14	36.2	61	95
V106	3	7.3	62.3	0.24	30.25	14.7	27.1	52	91
V107	2.8	9	66.3	0.13	21.19	15.7	26.8	52	88
V108	2.4	8	50.7	0.18	27.84	12.6	13.8	66	95
V109	2.8	7.5	62.3	0.22	37.11	11.7	29.8	62	92
V110	2.4	7.2	59.3	0.15	25.83	14.3	12	54	90
V111	2.7	8.3	69.7	0.15	28.39	15.7	16.1	53	91
V112	3.6	8.5	66.3	.	.	15.7	.	53	91
V113	2.3	7.3	55.7	0.29	32.06	13.7	26.2	60	93
V114	3.2	9.5	65.3	0.14	25.8	14.7	8	61	93
V115	2.7	8.5	46.5	0.21	30.45	14	21.7	63	94
V116	3.2	9.2	49.7	0.21	21.17	14	22.8	63	92
V117	2.8	8.5	56	0.12	19.8	12.7	16.2	61	91
V118	2.4	8.3	62.7	0.12	25.49	13	16.4	63	93
V119	3	9	74.3	0.27	31.5	12	23.3	52	89
V120	2.4	9.5	82	0.28	41.35	14	25.5	52	90
V121	2.7	8.7	63.3	0.22	26.41	15.7	30.6	52	90
V122	2.8	7.8	54	0.27	27.52	13.3	17.5	57	91
V123	2.6	8.2	61.3	0.12	23.05	13.3	25.6	64	93
V124	2.6	8.3	60	0.36	37.12	10.7	23.6	55	91
V125	2.3	8.5	64.7	0.22	25.14	12.3	21.8	60	91
V126	2.9	8.4	60.5	0.29	25.4	12.4	27.5	54	91
V127	2.2	8.7	52	0.23	25.09	12	21.2	57	91
V128	3	9	61	0.17	21.84	14	29.4	53	89
V129	2	7.3	61.7	0.22	31.9	13.7	15	57	91
V130	3.2	7.3	61.3	0.17	30.33	12.3	30	57	90
V131	2	9.2	57.3	0.24	30.07	13.7	18.1	60	97
V132	2.8	9.3	62.7	0.31	34.95	12.7	29.3	58	90
V133	1.8	7.7	55	0.27	26.05	11.7	19.7	57	91
V134	1.8	8.2	54.6	0.16	21.99	12.3	17.6	57	90
V135	3.3	8	58.7	0.22	36.8	12	30.6	53	88
V136	2.3	7.8	66.8	0.29	24.7	11	25.3	52	88
V137	2.2	7.8	47	0.07	25.78	11.3	12.8	62	93
V138	1.8	7.5	47.7	0.18	30.2	11	13.5	62	93
V139	2.3	7.7	58.8	0.22	35.13	11.7	15.2	56	90
V140	1.9	9.5	72.7	0.31	23.5	12.3	18.8	56	90
V141	1.6	10.2	58.7	0.12	37.5	11.6	15.4	59	91
V142	2.4	8	55.7	0.14	20.5	12.3	16	57	92
V143	1.5	8.7	44.3	0.24	40	11.7	21.6	60	94
V144	2	8.7	50	0.13	29.13	11.3	15	61	93
V145	1.5	8.2	53	0.21	35	11	22	57	92
V146	2.3	8.5	54	0.27	38.57	11	35	55	91
V147	2.3	8.3	63.6	0.22	32.7	10.4	22	50	89
V148	3	7.5	56	0.15	30.33	12.7	18	61	92
V149	2.1	9	72.7	0.21	29.65	13	36.8	54	90
V150	2.3	8.5	52	0.1	23.86	11.3	7	60	89

Entry No	Tillers /Plant	Ear Length	Plant Height	Harvest Index	Kernel Weight	Spikelets /Spike	Grain /Head	Days to Heading	Days to Maturity
V151	1.8	8.3	61.7	0.11	22.6	12	15.2	60	91
V152	2	8.7	54	0.19	28.69	12.3	19.8	60	91
V153	3.4	8	53.7	0.15	22.15	11.7	13	60	90
V154	3.2	9.7	52	0.1	25.9	12.3	16.2	64	96
V155	3	8.8	65	0.17	32.19	12.7	19	54	90
V156	2.6	8.7	54	0.12	36.09	14.3	22.2	62	93
V157	2.7	8.3	63	0.3	28.05	12.6	24.8	61	92
V158	2.7	8	56	0.11	35.8	12	19.5	62	92
V159	2.7	7.8	55.3	0.2	31.95	14.3	17.4	63	93
V160	2.8	8.2	58.7	0.16	28.7	11.6	23	61	91
V161	3.5	8.2	52	0.11	23.7	12.3	7.8	62	98
V162	2.5	7.7	59.3	0.13	16.3	12	15.8	57	91
V163	3	5.7	57.3	0.1	29.22	10.6	23.2	61	92
V164	3	8.3	58.7	0.19	28.97	13.3	24.2	57	92
V165	2.2	7.2	65	0.2	21.81	12.7	27	55	88
V166	2.7	7.2	57	0.2	32.44	12.7	35.2	53	89
V167	2.5	8.2	60.3	0.26	33.21	11.3	27.4	54	92
V168	2.6	7.2	57.3	0.33	33.16	9.9	18.6	51	89
V169	2	7.7	59	0.29	33.16	13	32.9	55	91
V170	2	7.5	51.7	0.18	26.8	10.7	8.4	54	92
V171	2	8.3	48.3	0.13	32.2	13	5.8	61	93
V172	2	8.7	53.7	0.08	19.3	12.7	12.2	61	93
V173	2.4	6.7	53	0.13	26.89	12	15	57	92
V174	1.4	9	51.3	0.11	25.55	13.7	21.1	62	96
V175	2	8.8	72.7	0.13	40.92	13.3	23.8	58	92
V176	2.8	8	70	0.2	37.4	12.3	7.8	59	92
V177	2.8	8	64.7	0.21	41.52	12.3	22.9	59	93
V178	2	7.8	56.8	0.16	24.13	11	15.8	59	93
V179	2.3	7.8	62	0.16	23.16	13.7	15.2	57	91
V180	2.6	7.3	59.7	0.11	26.25	12	12.8	54	90
V181	2.4	6.8	56.3	0.15	11.22	11	36.2	54	90
V182	2	8	64.3	0.25	27.9	11.3	21.7	55	92
V183	3.6	5.8	55.3	0.29	25.99	11.7	28.4	54	92
V184	3.2	8.7	62.3	0.13	20	12.7	10.3	58	88
V185	2.5	8.5	62.3	0.18	20	11.7	21	59	86
V186	1.5	8.5	63	0.24	38.22	12	23.9	56	88
V187	2.3	8.3	64.7	0.27	41.52	13.3	29	56	90
V188	1.8	7.7	57.7	0.26	30.67	11.7	35.6	57	89
V189	2.9	7.5	53.7	0.3	35.98	12.5	23.8	49	87
V190	2.6	9.3	55.7	0.18	28.73	12.7	21.6	62	93
V191	2.3	6.5	60	0.25	26.67	11.7	32.5	60	92
V192	3	8	53	0.17	29.43	14	9.8	58	92
V193	3.6	7	62	0.28	36.2	11.7	15.5	53	91
V194	1.8	6.8	71.3	0.21	18.8	12.6	28.7	57	87
V195	2.4	8	56.7	0.27	32.83	12.3	23.2	51	90
V196	1.8	7.5	54.7	0.12	19.15	12.6	14.3	58	90
V197	2	6.2	56.7	0.02	28.8	10.7	7.5	61	90
V198	2	7.3	58.7	0.08	24.85	12.3	27.6	58	90
V199	4.2	8	57	0.26	24.48	13.3	42.2	59	95
V200	3.5	8.8	48	0.3	33.1	11	26.9	48	89

Shaded cells are the Duma checks

Appendix C. Performance of SAWN entries in Elementaita NURSERY

VAR.	TLS	LH	H	H.I	KRNW	SPK	GRH
V1	2.7	7.3	45	0.34	33.36	11.3	27.4
V2	2.3	6.5	50.7	0.26	37.42	10.5	25.6
V3	2.3	6.3	49.7	0.32	29.92	11.3	25
V4	2.7	6.5	44	0.24	33.65	11	21.1
V5	3.3	6.7	52.7	0.22	35.57	12	24.4
V6	3.0	5.3	47.3	0.27	28.1	11	20
V7	2.5	5.5	52.3	0.35	30.93	9.5	14.8
V8	2.7	7.5	54	0.24	33.23	11.6	26
V9	3.0	7.7	54	0.27	35.59	12.7	23.6
V10	3.7	4	42	0.36	33.36	7	21.4
V11	2.0	5.5	50	0.1	31.04	9	15.4
V12	2.7	6.3	49.7	0.28	33.94	10.3	28.4
V13	2.8	6.7	49.3	0.21	35.95	11.3	26.2
V14	2.8	7	57.3	0.25	34.26	12.3	25.8
V15	2.7	7.7	55	0.37	33.2	12.7	26.4
V16	3.3	6.7	50	0.26	32.56	10.3	23.4
V17	2.3	6	45	0.25	27.14	11.4	26.6
V18	3.0	7.3	60.7	0.24	29.29	12	28.2
V19	3.7	6	58	0.3	32.95	11.3	31.2
V20	2.4	6	46.3	0.17	27.86	9.7	19.6
V21	3.0	8.3	47.3	0.25	36.74	12.7	25.8
V22	2.3	4.3	48.5	0.2	28.47	10	27.4
V23	2.5	5	42.3	0.17	27.85	8.3	18.6
V24	2.8	7.7	52	0.18	31.96	12.3	27.6
V25	3.0	5.3	43	0.25	33.93	13	22.4
V26	3.0	7.3	57	0.17	27.92	13.3	20.7
V27	2.8	7.7	59	0.27	31.5	12	25.2
V28	2.8	8.3	54.7	0.51	35.23	14	36.4
V29	2.8	6.3	63	0.3	32.88	13	26.4
V30	3.0	7.8	63.7	0.36	33.77	12.7	24.4
V31	2.5	7	50	0.28	22.93	13	24.6
V32	3.0	8.3	54	0.26	35	12.3	25.2
V33	3.5	5.5	54.7	0.3	29.38	10.5	12.8
V34	2.8	7.8	56	0.32	34.78	12.3	26.8
V35	2.5	7	58	0.3	37.57	12.3	28
V36	2.5	.	61	.	.	.	.
V37	3	8	58.3	0.28	37.24	12.7	29
V38	3	6	50.3	0.17	27.28	11.3	29
V39	4.3	5.3	46.3	0.29	34.11	11.7	31.6
V40	3.3	6.3	49.3	0.28	32.44	11.7	31.2
V41	2	6.7	46.7	0.21	33.14	9	14
V42	3	6	53.7	0.27	31.4	9.3	22.8
V43	2.8	7.7	48.3	0.34	32.54	11.7	26
V44	2.5	6	48	0.51	30.78	12	15.4
V45	3.8	8	58.7	0.35	36.28	13.6	29.6
V46	2.8	8	57.5	0.28	36.26	14	38
V47	3.2	9.7	48.7	0.36	33.1	15	33.6
V48	2.8	7.5	57.7	0.38	35.27	12	29.6
V49	2.5	4.3	49	0.3	34.79	8	23.8
V50	2.8	7	45	0.3	34.95	10.7	21.4
V51	2.8	6.5	56	0.22	27.33	10.7	23.2
V52	2.7	.	50.3	.	.	.	.
V53	2.8	6.5	44	0.28	31.52	11.5	30.2
V54	2.8	8	55	0.36	34.36	12.3	22
V55	3	.	58	.	.	.	.
V56	3.7	6.3	52.3	0.36	42.08	9	23
V57	3.3	6.3	50.3	0.4	34.06	12	24.6
V58	3	7.7	48.3	0.3	35.04	11.7	26.2
V59	3	7	55.7	0.32	37.01	12	17.4
V60	3.3	.	55	.	.	.	.
V61	2.3	.	47	0.32	.	.	.
V62	2.8	7.7	53.7	0.33	35.17	12.3	28.6
V63	3.3	8	58.3	0.34	32.93	12	33.4
V64	2.6	7.3	51	0.22	28.15	11.7	23.8
V65	2.8	8.5	56	0.26	33.97	13	26.2
V66	4	5.2	51	0.24	27.56	10.7	17.2
V67	3.3	6.5	56.3	0.38	38.96	9.7	30.8
V68	3	5.7	55.7	0.26	33.11	10.3	18
V69	3	.	45	.	.	.	.
V70	3.3	8	57.3	0.25	33.02	12	34.4
V71	2.8	9	61.3	0.27	35.97	15	29.8
V72	2.8	6.5	66	0.33	34.27	10	22
V73	4	7.8	56.3	0.35	34.96	12	23.4
V74	3	6.7	51	0.25	30.87	11	23
V75	3	.	51.7	.	.	.	.
V76	2.5	7.2	48	0.22	34.37	11.3	17.4
V77	3.3	7.7	59.3	0.26	34.96	13.7	27
V78	4	6.2	45	0.23	31.99	12.7	29.2
V79	2.6	8.3	48	0.47	37.18	13	28.4
V80	2.5	4.7	48.7	0.18	26.19	8.7	16.6
V81	3.2	5.3	49.5	0.35	29.29	14	34
V82	2.4	5	49	0.27	36.71	10	14
V83	3.3	8	57	0.29	31.88	11.7	27.6
V84	2.8	7	52	0.31	35.35	11.3	26
V85	3.3	8	56.3	0.23	31.13	13	26.6
V86	2.8	7.3	62	0.37	37.52	12	24.2
V87	4	.	55	.	.	.	.
V88	3.3	7	44.7	0.36	39.74	10.5	23.4
V89	3.3	6	53	0.24	34.88	9	17.2
V90	2.8	6.3	55.7	0.43	27.54	12.7	25.2
V91	3	6.5	52.7	0.2	25.54	12	18.4
V92	2.3	7.5	61.7	0.27	33.03	13.7	28.4
V93	3.3	8.3	56.3	0.37	34.68	14	31.2
V94	3.3	5.3	55.3	0.22	34.05	11.5	30.6
V95	3	6.3	50.3	0.31	39.05	11.3	29.4
V96	3	.	57.7	.	.	.	.
V97	2.5	6.8	49.3	0.56	36.99	11	29.2
V98	3.3	6.3	54.7	0.29	36.81	12	30.8
V99	2.8	5.3	51	0.25	31.3	12	26.2
V100	2.3	7.5	55.7	0.3	34.11	11.3	21.4
V101	2.5	6	37.3	0.22	23.68	9.3	22.7
V102	3.3	7.7	48	0.07	36.11	13	17

.R	TLS	L.H	H	H.I	KRN	SPK	GRH
03	2.3	7	49.3	0.26	29.83	13.7	32
04	2.8	6	46.3	0.25	33.09	12	24.6
05	2.7	7	46.3	0.38	36.22	11.3	19.6
06	2	5.5	45.7	0.33	28.19	12.3	22.7
07	2.8	6	36.3	0.14	24.4	9	18.8
08	2.7	6	33.7	0.27	30.47	11.5	21.2
09	2.7	6	48.7	0.21	28.89	11	23.4
10	2.3	6.3	51.7	0.27	31.81	10	16.6
11	2.6	6	46.7	0.38	28.41	10.7	27.6
12	2.3	7.3	50	0.2	30.79	13.7	28
13	3	6.3	53	0.26	31.38	13	24.6
14	2.5	6.3	48.3	0.29	27.16	11	14.8
15	4	7.3	51	0.21	26.53	13	20.2
16	2.8		46.7	0.25			
17	3.4	8	51	0.18	28.67	14	27.2
18	3.5	7.7	59	0.25	34.96	12	24.6
19	2.8	6.2	61.3	0.26	25.9	7.7	21
20	2.3	7.3	48.7	0.34	30.45	13	26.6
21	2.5	8.3	51	0.34	29.95	13.7	39.6
22	2.6	9	49.3	0.14	24.4	15	43.2
23	3	6.7	56	0.27	33.67	11	25.6
24	3.8	6	53	0.21	21.32	12.7	30.4
25	3.8		55				
26	2.3		44.7	0.29			
27	3	7.7	43	0.19	29.29	8.3	33.8
28	3	6.3	39.7	0.23	24.46	11	33.6
29	2.8	6.3	44.7	0.4	31.52	10.7	27.6
30	2.5		48.3	0.16			
31	2.5	7	44.3	0.36	25.73	10	19.2
32	3.5	8.3	49.7	0.25	30.6	13	23.2
33	2.8	6.7	45.7	0.46	32.33	12.3	32
34	2.5	7.3	48	0.32	33.11	13.7	39.2
35	2.5	8	47.7	0.24	27.31	11.3	29
36	2.8	5.3	45.7	0.3	36.57	8.7	14

VAR	TLS	LH	H	H.I	KRN	SPK	GRH
V137	4.3	8.7	60	0.23	29.45	14.7	36.4
V138	3	7.3	48.7	0.18	27.72	12	29.8
V139	3	6.7	55.7	0.37	33.35	12.3	32.8
V140	2.8	7.3	57.7	0.32	37.34	12.7	25.6
V141	2.8		55.7				
V142	2.5	6.7	55.3	0.25	33.36	11.3	23.2
V143	2.6	6.3	53.7	0.3	41.92	8.3	21.8
V144	3.3		53	0.18			
V145	3	7	46.3	0.42	33.17	11	25.2
V146	2.5	6	30	0.17	18.64	9.3	14.8
V147	2.5	7.7	50	0.23	31.81	9.3	23.2
V148	2.5	6.3	35	0.08	24.94	10.3	15.8
V149	2.3	6.3	40.3	0.25	23.27	11	20.2
V150	3	5.3	44.7	0.35	27.55	9.7	18.8
V151	2.3	5.3	40	0.26	29.3	9.7	14.2
V152	2.2		50.3	0.19			
V153	2.8	6.7	45	0.27	32.97	12	23.6
V154	2.2	7.3	48.7	0.25	31.14	12	21
V155	2.5	7	45.7	0.27	32.27	11	22
V156	2.3	7.3	45	0.19	29.72	11.7	29.4
V157	2.4	6.5	43	0.27	35.42	11	23.6
V158	2.5	6.7	44.3	0.23	35.81	10.7	27.2
V159	3	5.3	51	0.2	29.29	9.3	17
V160	3.5	7.7	54	0.4	34.3	13.7	26.2
V161	3.5	6.7	50.7	0.27	35.62	11	24.2
V162	2.5	7	51.7	0.34	37.17	14	36
V163	2	6	56.7	0.22	31.43	9.7	18.2
V164	3	6.3	50.3	0.32	31.82	12	22
V165	3	3.7	40.7	0.14	26	6.3	11
V166	2.8	6.7	50.3	0.22	32.6	9	20
V167	2		43	-			
V168	3.3	7.3	53	0.34	34.62	11.7	18.6
V169	2.3	7.7	53.3	0.32	28.64	13	22
V170	2.8	6.7	47.7	0.29	27.68	10	13.8

VAR	TLS	LH	H	H.I	KRN	SPK	GRH
V171	4.3	7	46.7	0.35	28.59	12.3	27
V172	2.3	6.8	43.7	0.32	26.13	10.7	16.4
V173	2.3	6	51	0.35	31.31	10.7	16.8
V174	2.8	6	46.7	0.23	26.67	12.3	15
V175	2	7.7	63	0.31	40.09	13	23.4
V176	3.8	8	70	0.3	41.48	11.7	29.8
V177	2.5	8	68.3	0.23	30.98	11.7	20.4
V178	2.5	7	57.7	0.22	31.1	11.5	20
V179	3.3	6.7	56	0.27	37.8	12	33.6
V180	3.3	5	54.3	0.2	29.53	11.7	25.8
V181	2.3		46.7				
V182	3	5	48.7	0.27	30.8	10.7	27.6
V183	2.5	8	38.7	0.5	35.1	11	23
V184	2.3	4	39	0.31	20	8.3	10.6
V185	3		51.7	0.16			
V186	2	8	42.3	0.32	29	15	28
V187	3.3		43.3	0.31			
V188	3.3	5.8	36.3	0.28	30.73	11	19.2
V189	2.5	6.2	41.7	0.43	25.74	10.3	23
V190	2.3	6	35	0.2	26.13	11	15.2
V191	3	6.3	41	0.23	28.91	10.7	25.8
V192	2.3	6.3	34	0.22	31.93	10.3	17.6
V193	2		35				
V194	3	5.5	29	0.16	21.17	9	12.8
V195	2		25				
V196	2.5		43.3	0.24	24.26		28.1
V197	2.3	4.7	50	0.27	31.32	10	33.4
V198	3	6.3	44.7	0.31	27.87	10.3	21.6
V199	2	7	38.7	0.15	28.55	10.7	16.6
V200	2.7	5.3	41	0.33	33.91	11.3	26.6

Shaded cells are the Duma checks

APPENDIX D PEDIGREE OF THE SELECTED ENTRIIES FROM THE 15TH AND 16TH SAWSN

ENTRY NO	PEDIGREE	SOURCE
7	BAU/ /COC CM100770-30Y-78-110RES-O30B-OY-OSY	15th SAWSN56
8	GOV/A/AZ/ /MUS/3/DODO/4/BOW CM79515-044Y-1M-O2Y-O7M-3Y-3B-OY-OPZ-2M-O10Y-OM-OSY	15th SAWSN61
9	GALUEZ S87 CM3483-C-7M-1Y-OM-58-OY-OMEX	15th SAWSN15
18	JUP/ZP/ /COC/3/PVN CM58705-3M-1Y-1M-1Y –1M-OY-2M-O10M-OM-OSY	15th SAWSN9
24	PATIO/ALO/ /PAT 72300/3/PVN/4/URES/5/PFOU CM87688-020TOPM-5Y-OH-OSY-1M-OY-OSY	15th SAWSN14
25	PYT1 K7874-2	Local cross
28	PGO/SERI CM85817-27Y-OM-OY-7M-OY-OSY	15th SAWSN21
34	PRINIA CM90722-23Y-OM-23-4Y-2Y-OM-OSY	15th SAWSN28
35	IRENA CM91575-7Y-OH-OY-2M-OY	15th SAWSN29
45	BJY/COC/ /PRL/BOW CM95439-54Y-OH-OSY-5M-ORES-OSY	15th SAWSN39
48	BJ/COC//PRL/BOW CM95439-54Y-OH-OSY-7M-ORES-OSY	15th SAWSN42
54	URES/JUN/ /KAUZ CM96818-1-OY-OM-O8-2Y-1Y-OM-OSY	15th SAWSN48
56	FILIN CM97334-OM-10Y-O30M-O30M-2Y-OY-OSY	15th SAWSN51
62	ARIVECHI M 92 CM100587-E-OM-OY-O30-8Y-1Y-OM-OMEX	15th SAWSN59
65	KAUZ/6/ATL66//H567.71//ATL66/5/PMN 5/ /S948.AL/4*CNO67/3/PMN5/4/CMH75A.66 cCM103327-29M-030M-020Y-010M-3Y-010Y-0M-OSY	15th SAWSN62
68	F60314.76/MRTL//CN079 CM7769-A-1Y-020M-O5Y-2B-1Y-OB	16th SAWSN14
71	CHIL/CHUM 18 CM92687-7PS-OY-O30M-TY-2Y-OY-2M-O1OY-0M-OSY	16th SAWSN31
73	BJY/COC/ /PRL/BOW CM95439-54Y-OH-OSY-5M-ORES-OSY	16th SAWSN39
76	FILIN CM97334-OM-10Y-O30M-O30M-4Y-OY-OSY	16th SAWSN52
77	FILIN CM97334-OM-15Y-O30M-O30M-3Y-OY-OSY	16th SAWSN53
129	R885	Local cross
136	R892	Local cross
162	NATA	Commercial variety
170	KWALE	Commercial variety
174	PASA	Commercial variety
	Duma check variety	Commercial variety

APPENDIX E. The rainfall data received during the growing season in Katumani and Elementaita.

Month	Katumani rainfall (mm)	Elementaita rainfall (mm)	No of rain days. (In Elementaita)
January	15	12.1	3
Fbruary	20	0	-
March	40	61.7	4
April	80	99.1	10
May	37	23.5	6
June	6	31.4	3
July	0	94	5
August	0	78	8
September	3	37	6
October	9	24.3	4
November	110	21.5	4
December	98	22.5	4

Appendix F . Grain yield (kg/ha) and relative yield (% of Duma check), of entries in 15th and 16th SAWSN grown in three Environments

	Katumani 1		Katumani 2		Elementaita			
Entry no	Yield lg/ha	% of Duma	Yield kg/ha	% of Duma	Yield kg/ha	% of Duma	MEAN	Drought score
1	314.50	48	567.25	48	256.75	46	379.50	2
2	335.00	51	925.00	79	787.50	142	682.50	1
3	597.83	91	732.75	63	474.00	85	601.53	2
4	558.17	85	575.50	49	124.50	22	419.39	2
5	258.67	39	94.25	08	712.75	128	355.22	1
6	668.16	101	813.75	69	471.75	85	157519	2
7	1212.15	184	1436.75	123	880.00	158	1176.3	2
8	897.00	136	1651.50	141	459.00	83	1002.5	3
9	913.50	139	817.50	70	475.00	85	735.3333	2
10	567.33	86	1008.25	86	533.00	96	702.86	1
11	964.00	146	1812.50	155	76.75	14	951.0833	3
12	467.17	71	955.50	82	419.25	75	613.9733	2
13	1012.83	154	592.00	51	463.50	83	689.4433	1
14	424.83	65	511.00	44	1169.25	211	701.6933	1
15	278.17	42	95.25	08	932.00	168	435.14	1
16	307.17	47	1006.75	86	448.75	81	587.5567	2
17	886.00	135	621.25	53	253.00	46	586.75	2
18	1131.50	172	585.00	50	846.75	152	854.4167	2
19	637.67	97	373.50	32	1132.25	204	714.4733	1
20	412.67	63	1069.75	91	259.50	47	580.64	2
21	415.15	63	1440.00	123	687.50	124	847.55	3
22	916.16	139	669.75	57	199.50	36	595.1367	2
23	411.33	62	332.50	28	305.75	55	349.86	3

Appendix F Cont'd

	Katumani 1		Katumani 2		Elementaita			
Entry no	Yield Kg/ha	% of Duma	Yield Kg/ha	% of Duma	Yield Kg/ha	% of Duma	MEAN	Drought score
24	1281.00	195	1772.00	151	543.00	98	1198.667	3
25	976.80	148	603.75	52	862.50	155	814.35	2
26	657.33	100	1475.00	126	386.25	70	839.5267	2
27	957.00	145	1158.50	99	547.00	98	887.5	2
28	637.50	97	1360.00	116	1155.75	208	1051.083	1
29	532.67	81	1497.75	128	526.50	95	852.3067	2
30	583.33	89	1319.00	113	545.00	98	815.7767	1
31	364.15	55	534.50	46	352.75	64	417.1333	1
32	452.33	69	728.25	62	385.50	69	522.0267	2
33	226.50	34	864.50	74	691.50	124	594.1667	2
34	255.00	39	1445.00	123	1215.75	219	971.9167	2
35	165.65	25	1943.25	166	1035.00	186	1047.967	1
36	529.00	80	357.50	31	–	–	443.25	1
37	302.33	46	1075.00	92	420.50	76	599.2767	2
38	258.83	39	843.00	72	212.25	38	438.0267	1
39	587.33	89	1321.75	113	357.75	64	755.61	1
40	670.00	102	521.75	45	497.25	90	563	2
41	547.00	83	473.50	40	104.00	19	374.8333	1
42	681.17	103	1363.50	116	405.75	73	816.8067	3
43	477.67	73	975.75	83	257.75	46	570.39	1
44	642.17	98	779.75	66	382.50	69	601.4733	1
45	707.84	108	840.25	72	954.25	172	834.1133	2
46	773.17	117	532.25	45	498.00	90	601.14	1
47	590.50	90	1081.75	92	721.00	130	797.75	2
48	846.00	129	640.75	55	958.25	173	815	1
49	367.83	56	1228.00	105	373.00	67	656.2767	2

Appendix F Cont'd

Entry no	Katumani 1 Yield Kg/ha	% of Duma	Katumani 2 Yield Kg/ha	% of Duma	Elementaita Yield Kg/ha	% of Duma	MEAN	Drought score
50	844.44	128	687.75	59	227.75	41	586.6467	1
51	938.83	143	460.25	39	323.00	58	574.0267	2
52	584.50	89	441.25	38	32.25	06	352.6667	1
53	636.33	97	966.00	82	734.50	132	778.9433	2
54	621.17	94	1607.00	137	622.00	112	950.0567	3
55	721.67	110	713.75	61	–	–	717.71	2
56	503.67	77	1286.75	110	907.25	163	899.2233	3
57	542.17	82	629.00	54	995.75	179	722.3067	1
58	626.15	95	342.50	29	520.75	94	496.4667	2
59	235.84	36	663.50	57	1280.50	231	726.6133	2
60	565.00	86	830.50	71	864.00	156	753.1667	2
61	697.33	106	1065.50	91	316.00	57	692.9433	2
62	1015.50	154	1362.50	116	749.75	135	1042.583	3
63	871.65	132	1789.50	153	1097.00	198	1252.717	3
64	866.00	132	674.50	58	219.75	40	586.75	2
65	1079.17	164	619.25	53	909.75	164	869.39	1
66	401.00	61	1894.75	162	366.50	66	887.4167	2
67	668.83	102	794.25	68	192.00	35	551.6933	2
68	908.00	138	915.00	78	912.00	164	911.6667	3
69	332.82	51	593.50	51	–	–	463.16	2
70	633.00	96	690.75	59	1245.00	224	856.25	2
71	1062.16	161	725.00	62	820.75	148	869.3033	3
72	378.50	57	771.00	66	1163.75	210	771.0833	3
73	894.65	136	955.25	81	615.75	111	821.8833	2
74	632.67	96	788.00	67	883.75	159	768.14	1
75	950.17	144	725.75	62	–	–	837.96	2

Appendix F Cont'd

Entry no	Katumani 1		Katumani 2		Elementaita			
	Yield Kg/ha	% of Duma	Yield Kg/ha	% of Duma	Yield Kg/ha	% of Duma	MEAN	Drought score
	Katumani 1		Katumani 2		Elementaita			
76	720.33	109	1150.25	98	868.75	156	913.11	2
77	1049.84	159	787.75	67	1551.75	279	1129.78	2
78	592.67	90	930.25	79	116.75	21	546.5567	3
79	485.00	74	355.00	30	232.50	42	357.5	1
80	226.33	34	330.25	28	138.00	25	231.5267	2
81	546.67	83	161.00	14	259.00	47	322.2233	1
82	329.67	50	997.75	85	342.00	62	556.4733	2
83	502.50	76	600.00	51	288.00	52	463.5	2
84	739.40	112	1658.25	141	633.00	114	1010.217	2
85	593.17	90	585.25	50	567.00	102	581.8067	1
86	150.33	23	697.75	60	822.25	148	556.7767	2
87	176.50	27	782.50	67	–	–	479.5	2
88	95.65	15	1571.50	134	273.00	49	646.7167	2
89	478.00	73	1606.00	137	417.50	75	833.8333	2
90	722.50	110	763.00	65	433.00	78	639.5	2
91	501.16	76	1162.25	99	201.00	36	621.47	2
92	510.50	78	1143.75	98	603.75	109	752.6667	3
93	405.83	62	1050.00	90	731.00	132	728.9433	3
94	506.00	77	512.25	44	274.25	49	430.8333	2
95	361.83	55	468.00	40	1088.75	196	639.5267	1
96	226.67	34	941.75	80	–	–	584.21	2
97	578.67	88	894.75	76	701.25	126	724.89	2
98	459.50	70	640.25	55	929.25	167	676.3333	3
99	563.83	86	603.00	51	253.50	46	473.4433	2
100	558.33	85	504.75	43	226.00	41	429.6933	1
101	375.83	57	692.50	59	55.50	10	374.61	1

Appendix F Cont'd

Entry no	Katumani 1		Katumani 2		Elementaita		MEAN	Drought score
	Yield Kg/ha	% of Duma	Yield Kg/ha	% of Duma	Yield Kg/ha	% of Duma		
102	431.00	65	1097.00	94	92.00	17	540	2
103	300.50	46	939.00	80	461.25	83	566.9167	2
104	333.33	51	1193.25	102	370.50	67	632.36	1
105	498.67	76	1064.50	91	472.25	85	678.4733	3
106	253.00	38	360.00	31	326.50	59	313.1667	2
107	757.67	115	348.75	30	103.75	19	403.39	2
108	753.50	114	489.50	42	204.75	37	482.5833	2
109	767.33	117	829.25	71	213.00	38	603.1933	1
110	127.33	19	520.00	44	136.25	25	261.1933	1
111	404.00	61	424.75	36	475.50	86	434.75	2
112	143.83	22	–	–	196.25	35	170.04	2
113	431.50	66	1226.25	105	529.75	95	729.1667	2
114	314.17	48	398.00	34	361.75	65	357.9733	2
115	512.33	78	569.25	49	411.25	74	497.61	2
116	316.50	48	669.25	58	408.75	74	464.8333	1
117	451.17	69	406.50	35	957.00	172	604.89	1
118	329.33	50	311.25	27	615.00	111	418.5267	2
119	308.67	47	748.75	64	893.00	161	650.14	3
120	232.16	35	850.50	73	596.50	107	559.72	3
121	352.83	52	1144.25	98	510.75	92	669.2767	3
122	269.83	41	1221.75	104	384.25	69	625.2767	2
123	470.00	71	594.25	51	1146.75	206	737	1
124	556.67	85	1153.75	98	313.25	56	674.5567	2
125	276.33	42	984.75	84	–	–	630.54	3
126	964.83	147	730.75	62	218.75	39	638.11	1
127	898.50	136	521.00	44	189.50	34	536.3333	2

Appendix F Cont'd

Entry no	Katumani 1 Yield Kg/ha	% of Duma	Katumani 2 Yield Kg/ha	% of Duma	Elementaita Yield Kg/ha	% of Duma	MEAN	Drought score
128	590.50	90	791.00	67	286.75	52	556.0833	2
129	1011.00	154	542.50	46	606.00	109	719.8333	2
130	1121.50	170	860.75	73	81.25	15	687.8333	2
131	1178.17	179	715.00	61	362.00	65	751.7233	3
132	388.33	59	1138.50	97	695.25	125	740.6933	3
133	778.33	118	681.25	58	461.00	83	640.1933	2
134	566.83	86	367.00	31	871.25	157	601.6933	1
135	304.33	46	440.00	38	551.25	99	431.86	1
136	841.50	128	1154.50	98	673.50	121	889.8333	1
137	1240.00	188	93.25	8	515.75	93	616.3333	1
138	489.33	74	264.25	23	455.25	82	402.9433	1
139	619.50	94	504.25	43	375.00	68	499.5833	1
140	373.67	57	393.25	34	637.50	115	468.14	2
141	426.17	65	202.50	17	_	_	314.335	2
142	146.83	22	353.50	30	307.75	55	269.36	2
143	294.50	45	546.00	47	455.25	82	431.9167	2
144	268.50	41	195.00	17	287.00	52	250.1667	1
145	216.00	33	525.25	45	742.25	134	494.5	1
146	555.17	84	755.00	64	216.00	39	508.7233	1
147	580.83	88	558.50	48	578.00	104	572.4433	1
148	203.67	31	438.75	37	102.00	18	248.14	2
149	177.33	27	794.75	68	352.25	63	441.4433	2
150	607.33	92	197.75	17	707.00	127	504.0267	1
151	382.33	58	386.25	33	129.50	23	299.36	2
152	160.50	24	472.00	40	291.75	53	308.0833	2
153	116.50	18	372.25	32	541.75	98	343.5	1

Appendix F Cont'd

	Katumani 1		Katumani 2		Elementaita			
Entry no	Yield Kg/ha	% of Duma	Yield Kg/ha	% of Duma	Yield Kg/ha	% of Duma	MEAN	Drought score
154	98.17	15	276.75	24	623.50	112	332.8067	1
155	502.50	76	780.75	67	546.75	98	610	2
156	551.33	84	560.75	48	334.50	60	482.1933	2
157	367.33	56	908.00	77	470.25	85	581.86	3
158	317.00	48	171.00	15	410.00	74	299.3333	2
159	508.33	77	879.50	75	455.75	82	614.5267	2
160	137.84	21	696.25	59	906.25	163	580.1133	2
161	369.50	56	379.25	32	479.25	86	409.3333	2
162	670.50	102	375.00	32	946.25	170	663.9167	2
163	728.17	111	373.50	32	449.50	81	517.0567	1
164	199.83	30	377.00	32	638.75	115	405.1933	1
165	338.50	51	614.00	52	67.50	12	340	2
166	238.67	36	768.00	66	279.00	50	428.5567	2
167	617.33	94	1123.00	96	–	–	870.165	2
168	603.83	92	1197.25	102	839.50	151	880.1933	3
169	244.00	37	856.75	73	554.75	100	551.8333	2
170	1048.60	159	403.25	34	652.50	117	701.45	2
171	674.65	102	302.75	26	779.75	140	585.7167	1
172	543.67	83	81.25	07	479.50	86	368.14	1
173	162.17	25	158.50	14	525.75	95	282.14	1
174	779.67	118	242.00	21	858.00	154	626.5567	1
175	430.17	65	466.25	40	1169.75	211	688.7233	2
176	466.33	71	663.75	57	1918.25	345	1016.11	3
177	400.18	61	850.75	73	747.75	135	666.2267	1
178	569.33	86	581.25	50	920.00	166	690.1933	2
179	479.67	73	606.25	52	670.50	121	585.4733	2

Appendix F Cont'd

Entry no	Katumani 1		Katumani 2		Elementaita		MEAN	Drought score
	Yield Kg/ha	% of Duma	Yield Kg/ha	% of Duma	Yield Kg/ha	% of Duma		
180	994.70	151	283.50	24	503.00	91	593.7333	2
181	471.15	72	602.25	51	–	–	536.7	2
182	270.50	41	753.75	64	273.25	49	432.5	1
183	203.83	31	1618.00	138	687.25	124	836.36	2
184	228.17	35	568.75	49	271.25	49	356.0567	2
185	175.33	27	938.50	80	80.50	14	398.11	3
186	366.68	56	1145.00	98	803.25	145	771.6433	3
187	775.00	118	1371.25	117	229.50	41	791.9167	3
188	513.33	78	1148.00	98	210.75	38	624.0267	2
189	801.50	122	1150.75	98	216.75	39	723	2
190	778.33	118	673.00	57	227.25	41	559.5267	1
191	400.67	61	630.00	54	145.25	26	391.9733	2
192	718.83	109	463.00	40	108.25	19	430.0267	2
193	703.83	107	1039.25	89	–	–	871.54	2
194	261.83	40	1132.50	97	40.75	07	478.36	2
195	566.67	86	1158.75	99	–	–	862.71	2
196	254.83	39	261.50	22	119.50	22	211.9433	1
197	593.33	90	73.00	06	239.00	43	301.7767	1
198	135.50	21	200.75	17	154.75	28	163.6667	1
199	719.33	109	1038.25	89	110.00	20	622.5267	2
200	413.00	63	768.25	66	405.75	73	529	1
Local check (Mean)	657.00	100	1172.12	100	555.42	100		

Shaded cells are the Duma checks