ASSESSMENT OF YIELD, GRAIN QUALITY AND COMBINING ABILITY OF SELECTED RICE CULTIVARS IN KENYA

By

BRYAN ELWICH JOHN DENIS

B.Sc. Biotechnology (Hons), University of Juba, Khartoum

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN PLANT

BREEDING AND BIOTECHNOLOGY

DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION, FACULTY OF AGRICULTURE, COLLEGE OF AGRICULTURE AND VETERINARY SCINCES

UNIVERSITY OF NAIROBI

2019

DECLARATION

This thesis is my original work and has not been presented for award of a degree in any other University.

Signed............................ Date...27/11/2019.

Bryan Elwich John Denis

This Thesis has been submitted for examination with our approval as University supervisors:

Prof Kahiu Ngugi

Department of Plant Science and Crop Protection

University of Nairobi

Signed............................ Date 27/11/2019

Dr. Lydia Nanjala Wamalwa

Department of Plant Science and Crop Protection

University of Nairobi

Signed............................ Date......27/11/19........

Dr. John Kimani

Kenya Agricultural and Livestock Research Organization (KALRO)

Industrial Crops Research Centre, Mwea

Signed............................ Date...28/11/2019...

ii

DEDICATION

This thesis is dedicated to the Almighty God, my father Johnny Dennis Okeny, my mother Karlina Achayo Mario and my daughter Rachael Aribo Bryan.

ACKNOWLEDGEMENT

I am grateful to Almighty Father for giving me the life, guidance and strength to make this study a success. With deep sense of appreciation, I thank my parents for financial and academic support without which I could not have done this study.

I express my special thanks and gratitude to my supervisory team of Prof Kahiu Ngugi, Dr. Lydia Wamalwa and Dr. John Kimani for their guidance, encouragement, support and valuable comments. I also express my sincerely grateful and appreciation goes to Kenya Agricultural Research and livestock Organization (KARLO) Mwea and staff members at the Centre for their technical support, and I also acknowledge the use of rice germplasm developed by KAFACI, AGRA and BBSRC Projects from KARLO-Mwea.

Lastly special thanks to my uncle, my brothers and sisters who have been source of inspiration. I greatly appreciate my uncle and his wife (Methew Okongo and Arafa Naftali) who offered me a place to stay during my study in Nairobi (Kenya), God blesses you all.

TABLE OF CONTENTS

DECLARATION .... **Error! Bookmark not defined.**

DEDICATION iii

ACKNOWLEDGEMENT iv

TABLE OF CONTENTS v

LIST OF ABBREVIATIONS xi

LIST OF SYMBOLS xii

ABSTRACT xiii

CHAPTER ONE: INTRODUCTION 27

1.0 Background Information 27

1.1. Rice Production, Consumption and Importance in Kenya 28

1.2. Constraints in Rice Production in Kenya 30

1.3. Problem Statement 30

1.4. Justification 31

1.5 Overall objective 31

CHAPTER TWO: LITERATURE REVIEW 33

2.0 Taxonomy 33

2.1. Origin and distribution of Rice 34

2.2. Rice Consumption in the World 35

2.3. Rice Ecosystem and Hydrological Conditions 35

2.4. Rice Varieties Grown in Kenya 37

2.5. Grain Quality in Aromatic Rice 39

2.5.1. Grain dimension 41

2.5.2. Kernel Elongation 41

2.6. Genetic Improvement of Rice Cultivars 42

2.7. General and Specific Combining ability Concepts 43

2.8. Mating designs in Rice 44

2.9. Heritability of yield and yield components in Rice 47

2.10. Correlations among yield Components in Rice 47

CHAPTER THREE: EVALUATION OF RICE CULTIVARS FOR GRAIN YIELD, QUALITY TRAITS AND EARLINESS 49

3.0 Abstract 49

3.1. Introduction 50

3.2. Materials and Methods 51

3.2.1. Experimental Site 51

3.2.2. Population generated and Germplasm Evaluated 52

3.2.3. Design and crop husbandry 53

3.2.4. Agronomic Traits Studied 54

3.3. Data Collection 55

3.3.1. Grain Quality 55

3.4. Data Analysis 56

3.4.1. Estimation of variance components 56

3.4.2. Phenotypic and Genotypic coefficient of Variation 56

3.4.3. Heritability (broad sense) Estimation 57

3.4.4. Phenotypic Correlation 57

3.5. Results 58

3.5.1. Agronomic Performance of rice cultivars across Seasons 60

3.5.2. Phenotypic Correlations 65

3.5.3. Grain Quality Performance 50

3.5.4. Estimation of Mean, genotypic, phenotypic and environmental variance 2016/2017. 51

3.5.5. Genotypic coefficient of variation, phenotypic coefficient of variation and broad sense heritability. 52

3.6. Discussion 54

CHAPTER FOUR: COMBINING ABILITY FOR YIELD COMPONENTS AND QUALITY TRAITS IN UPLAND RICE CULTIVARS.......... 60

4.0 Abstract 60

4.1. Introduction 62

4.2. Materials and Methods:.......... 63

4.2.1. Study Location:.......... 63

4.2.2. Plant materials:.......... 63

4.2.3. Hybridization 63

4.2.4. Harvesting of F1 seeds.......... 64

4.2.5. Evaluation of F1 Progeny 64

4.3. Data Collection:.......... 64

4.4. DATA ANALYSIS 64

4.4.1. Combining Ability Analysis: 65

4.4.2. Estimation of General and Specific combining Ability effects 65

4.5. Results 66

4.5.1. GCA and SCA for Agronomic and Yield Traits.......... 70

4.6. Discussion 74

4.7. Conclusion.......... 76

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS 77

5.0. GENRAL DISCUSSION AND CONCLUSION.......... 77

5.1. RECOMMENDATIONS 78

REFERENCES 79

LIST OF TABLES

Table 1.1: Kenya milled rice production, area and yield from years 2008 – 2010………………3

Table 1.2: Kenya paddy rice Trade and Consumption (Tonnes), from years 2008 – 2013……………...4

Table 2.1: Irrigated rice varieties grown in Kenya and their characteristics ………………….......15

Table 3.1: Rice genotypes grown in Kenya with different attributes screened for grain quality, earliness and yield………………………………………………………………...29

Table 3.2: Analysis of Variance for Agronomic Traits for at Mwea Research Station Farm………………………………………………………………………...36

Table 3.3: Performances of yield and its components for 14 genotypes studied at Mwea Research Centre (season 2016) …….…………………………………………………….....40

Table 3.4: Performances of yield and its components for 14 genotypes studied at Mwea Research Centre (season 2017)…………………………………………………………....,,41

Table 3.5: Performances of yield and its components for 14 genotypes studied at Mwea Research Centre (Combine seasons)………… ……….……………………………............42

Table 3.6: Phenotypic correlation coefficients for grain yields and its components for season 2016 ………………………………………………………………………………46

Table 3.7: Phenotypic correlation coefficients for grain yields and its components for season 2017..47

Table 3.8: Simple correlation coefficients for grain yields and its components for combine Seasons…………………………………………………………………………...48

Table 3.9: Mean Performance of Grain Quality traits among the rice genotypes………………49

Table 3.10: Estimate of environment, genotype and phenotypic variance for 14 traits evaluated at Mwea for combine seasons……………………………………………………....51

Table 3.11: Coefficients of genotypic and phenotypic variations; heritability and genetic advance (as % of population mean) for 14 traits of rice at Mwea for season 2016 and 2017 ………………………………………………………………………………..53

Table 4.1: North Carolina Mating Design II used to generate rice populations for estimating GCA and SCA………………………………………………………………….64

Table 4.2: Analysis of Variance (ANOVA) for different Agronomic and Yield Traits………..70

Table 4.3: Analysis of variance for combining Ability of 10 parents and their 21 F_1 hybrids for different yield characters……………………………………………………………….71
Table 4.4: General Combining Ability effects for 10 Parents for different yield characters…...71
Table 4.5: Specific Combining Ability for 21 F_1 hybrids for different yield characters………………73

LIST OF ABBREVIATIONS

ARC	Africa Rice Center
B.C	Before Christ
CAN	Calcium ammonium nitrates
DAP	Di-ammonium phosphate
GA	Genetic Advance
GDP	Gross Domestic Product
IRRI	International Rice Research Institute
KARLO	Kenya Agriculture Research and Livestock Organization
L/W	The length to width ratio
MAFAP	Monitoring and Analyzing Food and Agriculture Policies
MOA	Ministry of Agriculture
MT	Metric Ton
N.I.B	National Irrigation Board
NRDS	National Rice Development Strategy
RYMV	Rice Yellow Mottle Virus
SES	The standard evaluation system
SSA	South Saharan Africa
TGW	Thousand grain weight

LIST OF SYMBOLS

%	Per cent
σ^2A	Additive genetic variance
σ^2D	Dominance genetic variance
° C	Degree Centigrade
Cm	Centimeter
et al.,	And others
F_1	First filial generation
F_2	Second filial generation
G	Grams
>	Greater than
<	Less than
≤	Less than or equal to
$^{\delta}A/^{\delta}D$	Additive to dominance ratio
Q^2g	Genotypic variance
Q^2p	Phenotypic variance
Q^2e	Environmental variance
Ha	Hectare
Kg	Kilogram
Mm	Millimeter

ABSTRACT

Rice is an important crop in Kenya, mostly grown by small scale farmers as a commercial and food crop. The existing cultivars are low yielding, late maturing, and low grain quality. There is need to improve locally adapted cultivars to be high yielding and have desirable grain qualities. This study was aimed at evaluating rice cultivars for performance and combining ability of yield and grain quality traits.

Thirty one genotypes, comprising of parental lines and F_1 progenies were sown in a randomized complete block design in Mwea Research Station of KARLO during 2016/2017 rainy seasons. The genotypes were scored for grain yield, grain quality and other agronomic traits and data analyzed using GenStat 15th Edition program.

There were significant differences among genotypes for all the traits studied. Genotypes, Nerica 1, Nerica 2 and Basmati 370 were early maturing; Basmati 370 had higher grain yields in all the seasons indicating wide adaptability. Generation of cross NERICA 10 x MWUR 4 exhibited slender grain shape. Genotype Basmati 370 had strong aroma, NERICA 3 x Basmati 370, NERICA 2 x Basmati 370 and NERICA 1 mild aroma, but those of K1-99 x KOMBOKA and NERCA 10 were non aromatic. Grain yield was positively correlated with days to maturity, plant height, number of productive tillers, number of filled grains and 1000 grain weight and negatively correlated with number of empty grains.

Out of the 10 cultivars, evaluated for general combining ability, three cultivars Basmati 370, (0.88**), Nerica 3 (0.42**) and Nerica 2 (0.36**) were high general combiners for yield. From 21 hybrids evaluated for specific combining ability, three crosses namely, Mwur 4 x Nerica 3 (0.71**), Dourado x Nerica 1 (0.24**) and Komboka x Basmati 370 (0.21**) had high combining values for grain yield. Cultivars with high GCA for grain yield such as Basmati 370 and Nerica 2 turned out to have low SCA values as shown in generation of crosses Dourado x Basmati 370, Komboka x Nerica 2 and Mwur 4 x Basmati 370. General combining ability (GCA) variances were higher than specific combining ability (SCA) variances indicating that additive genetic effects were more important in determining genetic variability than dominance effects.

From the results obtained in this study, improvement for grain yield would be easier through indirect selection of yield components traits such as days to maturity, number of productive tillers per panicle, number of filled grains per panicle and thousand grain weights. However, there is need

to advance the segregating populations to F_3:F_4 generations in order to ascertain their agronomic, grain quality and yield potential in multi-location trials.

Keywords: Rice (Oriza Sativa) combining ability for grain quality, grain yield and earliness

CHAPTER ONE: INTRODUCTION

1.0 Background Information

Rice is the most important crop in the world alongside other cereals such as wheat and maize (Khalil, 2016). Rice is one of the highest valued crops in the world and the major food source for more than half of the world's population (IRRI, 2010). Unlike most food crops, rice is generally eaten whole without seasoning, making the sensory properties especially aroma desirable and unacceptable to consumers (Yau and Liu, 1999).

Rice cultivation is the principal activity and source of income for about 100 million households in Asia and Africa (FAO, 2004; Umadevi et al., 2012). Besides having nutritional and medicinal benefits, by-products from growing rice create that are discarded through the milling process and the edible part could be transformed into useful products (Umadevi et al., 2012).

Over 2 billion people in Asia alone derive 80% of their energy needs from rice, which contains 80% carbohydrates, 7-8% protein, 3% fat, and 3% fiber (Juliano, 1985). Until recently, rice was considered only a starchy food and a source of carbohydrates and some amount of protein. Rice protein, though small in amount, is of high nutritional value (Chaudhary and Tran, 2001).

Although rice is produced over vast areas of the world, the physical requirements for growing rice (available water, soil types) are limited to certain areas. These usually involve high average temperatures through the growing season, a plentiful supply of water applied in a timely fashion, a smooth land surface to facilitate uniform flooding and drainage, and a subsoil hardpan that hinders the percolation of water, mostly in tropical and subtropical regions and accounts for more than 75% of worldwide trade (FAO, 1999).

Indica rice cooks dry, with separate grains. Japonica rice, characteristically grown in regions with cooler climates, accounts for about 8 % of global rice trade (FAO, 2006) . Aromatic rice, primarily jasmine from Thailand and basmati from India and Pakistan, accounts for around 15% of global trade and typically sells at a premium in world markets glutinous rice, grown mostly in Southeast Asia and used in desserts and ceremonial dishes (Second et al., 1982). In addition to the major varieties, several others specialty rice include cultivars of India and Bangladesh, Ashinas cultivars of Bangladesh and Basmati cultivars of India accounts for most of the remainder (Garris et al., 2005).

Rice is the only cereal crop cooked and consumed mainly as whole grains, and quality considerations are much more important than any other food crop (Hossain et al., 2009). Although production, harvesting and postharvest operations affect overall quality of milled rice, cultivars remains the most important determinant of market and end-use qualities. Quality desired in rice varies from one geographical region to another and consumer demand for certain cultivars and favors specific quality traits of milled rice for home cooking (Juliano et al., 1964; Azenz and Shafi, 1966). Hybrids must have high grain quality that is at least comparable, if not superior to that of high yielding cultivars. However, the efforts in the improvement of grain quality of hybrid rice are very limited.

Rice is the third most important staple food in Kenya after maize and wheat (Wagara 2007). The availability of rice shows its relative importance for different group of consumers. For low income consumers in Nairobi, rice accounts for 3.9% of food expenditure compared to 11.9% and 10.7% for maize and wheat (Syed and Khaliq, 2008).

1.1. Rice Production, Consumption and Importance in Kenya

Rice was introduced in Kenya in 1907 from Asia (MOA 2009 NRDS 2008-2018). Though many regions grow the crop for domestic consumption, Kenya for long time regarded rice as a cash crop. This long held perception is, however, rapidly changing, with many communities now appreciating the importance of rice a food crop for domestic consumption in addition to being a cash crop for income generation (Onyango, 2014). This change in perception has greatly influenced the balance between production and consumption of rice in Kenya.

There are two main rice production systems in Kenya, namely irrigated rice and rain-fed rice productivity. The irrigated areas cover approximately 13,000 ha and include irrigation schemes in Nyanza west Kano and Ahero (at 3,520 ha), western Bunyala scheme (at 516 ha) and Mwea irrigation scheme (at 9,000 ha) (MOA, 2011). The average production under irrigation is 5.5 tons/ha for the aromatic variety and 7 tons/ha for the non-aromatic varieties (MOA, 2013).

There are several of rice estimates in production, area and yield in Kenya. The two most cited are those of Ministry of Agriculture (MOA) for milled production and those of National Irrigation

Board (NIB) for paddy rice production on its irrigation schemes (Table 1.1). The current rice production in Kenya varies between 43,000 to 80,000 MT, while the consumption is well above 300,000 MT (2005 – 2010) (MOA 2010), this has led to the need to develop new improved rice cultivars and created an opportunity for farmers to venture into rice production. About 80% of rice grown in Kenya is under irrigation in paddy schemes established by the government, and about 20% of the rice is produced under rain-fed conditions (MOA, 2010).

The current rice cultivars in Kenya are grown at altitude range from 0 to 1700 meters above sea level with temperature requirement range of 17^{o} C to 34^{o} C. The varieties are grouped according to the ecosystem. Irrigated varieties include: Sindano, Basmati 217 (*Pishori*), Basmati 370 (*Pishori*), BW 196, BR 51- 74-6, BG-90-2, ITA 310 and IR2793-80-1: the rain-fed upland cultivars include Dourado Precoce,TGR-94,Nam Roo and the NERICA 1,4,10,11 (New Rice for Africa). Rain-fed lowland (swampy) zones varieties include: Jasmine-85, TGR-78 and WABIS 675 (Kimani et al., 2011). In Mwea, about 98% of the rice cultivars cultivated is the popular basmati known for its superior grain quality trait. Rice yields have been declining over time due to poor agronomic practices, poor quality seeds and low yielding varieties (MOA, 2010).

There are four major rice mills spread across the country with varying capacities, Lake Basin Development Authority (LBDA) has milling capacity of 3.5 MT, Mwea NIB has a milling capacity of 24 Metric Tons (MT) per hour, western Kenya rice mills has 3 MT per hour while Tana Delta has 3 MT per hour (MOA, National Rice Development Strategy 2008 – 2018).

Table 1.1 Kenya milled rice production, area and yield from years 2008 – 2010

	Unit	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
MOA Estimate							
Production	Ton	21881	42,202	85,536	111,229	122,465	146,696
Area	Ha	16734	21,829	20,181	28,031	25,197	28,000
Yield	T/ha	1.3	1.9	4.2	4.0	4.9	5.2
NIB Estimates		**2008**	**2009**	**2010**	**2011**	**2012**	**2013**
Productions	Ton	25041	23249	47,125	52,159	54,322	58,812
Area	Ha	9092	10072	17,611	21,101	21,872	21,313
Yield	T/ha	2.8	2.3	2.6	2.5	2.5	2.8

Source: MAFAP (2013), (Short et al., 2013 and MOA 2010)

Rice consumption has been growing much more rapidly than production throughout the nearly 50 years since independence. Consumption has grown at an average rate of 11% per year since 1960.

As a result, imports have increased rapidly and the dependency ratio has climbed higher in most decades since 1960 averaging 23% in the 1960, 15% in the 1970, 53% in the 1980 and 88% in the 1990. The growth in consumption appears to have slowed to 3 percent per year since 2005, but the dependency ratio for the decade remains at 88%. Table 1.2, below shows milled rice trade and consumption for the period, 2008-2013.

Table 1.2. Kenya paddy rice Trade and Consumption (Tonnes), from years 2008 - 2013

	2008	2009	2010	2011	2012	2013
Production	21,881	42,202	45,313	72,299	82,159	95,317
Imports	299,070	308,158	398,000	408,771	417,535	500,258
Export	1,481	2,310	1,640	11,945	11,845	6,419
Apparent Consumptions	319,470	348,050	383,000	520,000	577,600	646,900
Import dependency ratio	93%	87%	86%	79%	72%	77%

Source: MOA 2010

1.2. Constraints in Rice Production in Kenya

The major constrains affecting rice production in Kenya include biotic and abiotic factors, poor crop management practices and socio-economic constraint. Drought stress is amongst the key abiotic factors that impede production. Drought stresses occur in regions where the soils are highly weathered and the foremost clay is usually kaolinite with low water-retention capacity. In upland rain-fed ecology, the drawbacks are due to little or no fertilizer applications, delayed weeding and drought.

Other biotic stress factors include insect pests, birds, mice and the large rodents known as "grasscutters" (*Thryonomis swindarianus*). Among the diseases, blast, leaf scald, brown spot and sheath rot and Rice Yellow Mottle Virus (RYMV) cause considerable yield losses (Jeandroz et al., 2017).

1.3. Problem Statement

Rice plays a key role in providing food and nutritional needs in Kenya. In Kenya, the most constraint in rice production are low yielding, un-adapted varieties of poor grain quality unacceptable to farmers and consumers. The current paddy rice cultivars have undesirable cooking aroma because they lost their purity, original grain quality traits and have become prone to diseases and pests (Kimani et al., 2011). The locally produced rice is unable to compete with the imported rice that has improved cooking and eating qualities. Aroma and flavor are ranked as the most important preference in grain quality, and some of the adapted cultivars do not have those sensory properties (Diako et al., 2010).

1.4. Justification

Rice quality is primarily assessed based on physical properties such as head rice recovery, chalkiness, grain size and shape. Other traits such as aroma have extra value. In Kenya, consumers prefer aromatic rice with long grain which has superior cooking qualities compared to other local cultivars and the local production is very low to meet the demand. Improving the yield potential, grain quality and grain quality of upland rice varieties of *indica* and *japonica* rice may be more sustainable way of increasing rice production in the community. Determining the general and specific combining ability in the rice varieties will show the importance of non and additive gene action in the expression of agronomic and yield traits (Sathya and Jebaraj, 2015).

Yield is the most noticeable characteristics to farmers while the crop is in the ground, but when the product of the crop, the milled rice reaches the market, quality becomes the key determinant of its sale ability.

Early-maturing and high yield varieties with good grain quality are very useful for increasing rice production in Kenya. Rice cultivars with short duration has important feature and it allows farmers to increase crop intensity from one to two crops of rice per year.

To improve the rice grain quality, major focus on improving and developing rice cultivars through conventional breeding with affordable high rice quality not only meets preferences of its fast-growing and increasingly population, but also competes with imported rice.

Objectives:

1.5 Overall objective

To evaluate yield, grain quality and combining ability of selected cultivars in Kenya.

1.5.1 Specific objectives

1) To evaluate rice cultivars for grain yield, earliness and grain quality traits.
2) To determine the combining ability for yield and grain quality traits in upland rice cultivars.

1.5.2 Null Hypothesis

1- There are no significant differences in grain yield, earliness and grain quality traits among rice cultivars.

2- Additive and non-additive gene actions are not significant in the expression of yield and grain quality.

CHAPTER TWO: LITERATURE REVIEW

2.0 Taxonomy

Rice, like wheat, corn, rye, oats, and barley belongs to Gramineae or grass family. Rice belongs to the genus *Oryza* and the tribe *Oryzeae* of the family Gramineae (Poaceae). The genus Oryza contains 25 recognized species, of which 23 are wild species and two *Oryza Sativa* (which is more widely used) and *Oryza glaberrima* (referred to as African rice) are cultivated (Vaughan 1994). The two cultivated species of rice are native to tropical and sub-tropical Southern Asia and South-eastern Africa, respectively (Linares, 2002). The African rice *Oryza glaberrima* is thought to have originated from a cross between *Oryza barthii* and *Oryza longistaminata* (Vaughan et al., 2003). The common rice, *O. sativa* and the African rice, *O. glaberrima* are thought to be an example of parallel evolution in crop plants. The wild progenitor of *O. sativa* is the Sian common wild rice, *O. rufipogon*, which shows a range of variation from perennial to annual types. Annual types, also given specific name of *O. nivara*, were domesticated to become *O. sativa*. In a parallel evolution path, *O. glaberrima* was domesticated from annual *O. breviligulata*, which in turn evolved from perennial *O. longistaminata* (Sharma et al., 2000). *O. rufipogon* is disseminated from Pakistan to China and Indonesia and its populations differ between perennial and annual types, which fluctuate markedly in life history traits (Okra, 1988). In short, the perennial kinds have higher out crossing rates and lower seed productivity than annual types (Oka and Morishima 1967).

Rice has long been the food staple in many traditional rice growing communities and in major cities in Africa. It has now become the fastest growing food staple across the continent. Rice is generally associated with Asia, but it is also an integral part of the history and culture of Africa, where it has been grown for over 3000 years. The development of the NERICA varieties began in 1991 when African Development Bank (AFD) sponsored the initiation of an interspecific breeding program for the upland ecosystem. This long term investment paid off and breeders were able to overcome the obstacles encountered earlier through perseverance and use of biotechnology tools such as anther culture and embryo rescue techniques. NERICA varieties were developed from crosses between the African species (*O. glaberrima* Steud.) and the Asian species (*O. sativa* L.) using conventional biotechnology to overcome the sterility barrier between the two species. NERICA is, therefore, an inter-specific variety but not genetically modified. Out of the thousands of crosses that were done, Africa Rice project distinguished two families of elite material that have been adopted in many sub-Saharan African countries and that were named NERICA varieties: 18 varieties suited for upland systems (NERICA1 to NERICA18) and 60 varieties suited for lowland systems (NERICA-L1 to NERICA-L60) (WARDA, 2008)

2.1. Origin and distribution of Rice

The African cultivated rice, *O. glaberrima* was domesticated in Niger River delta. The main center of diversity for *O. glaberrima* is the swampy basin of the upper Niger River and two minor canters to the southwest near the Guinea Coast. The primary centers were probably formed around 1500 BC while the secondary centers were formed 500 years later (Porteres, 1956). The center of origin and centers of diversity of two cultivated species *O. sativa* and *O. glaberrima* have been identified using genetic diversity, historical and archaeological evidences and geographical distribution. It is largely agreed that river valleys of Yangtze, Mekon Rivers could be the primary centers of origin of *O. sativa* while Delta of Niger River in Africa as the primary center of origin of *O. glaberrima* (Porteres, 1956; OECD, 1999). The foothills of the Himalayas, Chhattisgarh, Jeypore Tract of Orissa, northeastern India, northern parts of Myanmar and Thailand, Yunnan Province of China etc., are some of the centers of diversity for Asian cultigens. The Inner delta of Niger River and several areas nearby Guinean coast of the Africa are considered to be center of diversity of the African species of *O. glaberrima* (Chang, 1976; Okra, 1988).

Presently rice is grown worldwide in both temperate and tropical climates with major grown regions found in Asia, Latin America and Africa, but the foremost exporting countries include Thailand, the United States, Vietnam and Pakistan. It is estimated that 85% of total rice production is for human consumption (Nguyen, 2001)

Rice is distributed all over the world including all the countries in Asia, most of the countries of West and North Africa, some countries of East and Central Africa, most of the South and Central America countries and Australia (Li, 2003). From the Himalayan foot hills rice spread to Western and Northern India, to Afghanistan and Iran and South to Sri Lanka (Khus, 1997). The data of 2500 BC has previously been mentioned for Mohenjodarao, while in Sri Lanka rice was a key crop as early as 1000 BC. The rice crop may well have been introduced to Greece and neighboring countries of Mediterranean by returning members of Alexander the Great's expedition to India in 324BC (Khus, 1997). However, in all possibility rice did not become an established crop in Europe much later maybe in 15th or 16th century. Rice grown in the Mediterranean region is japonicas although the rice grown in the Indian subcontinent is indicas. Rice also travelled from India to

Madagascar and East Africa and then to countries of West Africa (Kirk, 1998). Indica rice also spread eastward to Southeast Asia and north to China (Dingkuhn, 1998).

2.2. Rice Consumption in the World

Roughly 50% of consumed calories by the whole population of humans depend on wheat, rice and maize (Global Rice Science Partnership, 2013). Although rice has the second place as of planted area, but it serves as the most essential food source for Asian countries mainly in South-east parts where it is an economic crop for farmers and workers who grow it on millions of hectares through the region (Zibaee, 2013).

Africa has developed into a big player in international rice markets, accounting for 32% of global imports in 2006, at a record level of 9 million tons that year. Africa's emergence as a big rice importer is explained by the fact that during the last decade rice has become the most rapidly growing food source in SSA (Sohl, 2005). Rice has also become an important plant and staple food for millions of Western Africa .The annual demand for rice in the sub-region is estimated at over 8 million MT (Africa Rice, 2013). Due to population growth (2.6% per annum), rising incomes and a shift in consumer preferences in favor of rice, especially in urban areas, the relative growth in demand for rice preservation and cooking have influenced the growing trend in rice consumption faster in this region OF SSA (Rapu, 2016), occurring throughout the sub-regions of sub-Saharan Africa (Balasubramanianet al., 2007).

2.3. Rice Ecosystem and Hydrological Conditions

Rice farming is practiced in numerous agro-ecological zones, although most of the rice farming occurs in warm/cool humid sub-tropics, warm humid tropics (AEZ 3), and in warm sub-humid tropics (World Bank Projections, 1994-95). Rice production systems differ broadly in cropping intensity and yield, ranging from single-crop rain-fed lowland and upland rice with small yields (1-3 t-ha), to triple irrigated systems with an annual grain production of up to 15-18 t-ha. The four types of environment for growing rice includes: irrigated system, rain-fed lowland ecosystem, deep water ecosystem and upland ecosystem.

Irrigated system covers about 55% of world rice overall production area (Tripathy et al., 2011). Possibly 75% of the world rice production is from irrigated areas (Guo, 2013), and productivity is high due to fertile paddy fields with good drainage not prone to flooding or drought (Bouman et al., 2007). Rice yields in irrigated ecosystem areas have more than doubled to five tons per ha, and most of the irrigated areas are sown with improved cultivars and high amount of fertilizers than in other ecologies (Sohrabi, 2012). The irrigated ecosystem is the most reliable production system of rice cultivation in Africa. A gradual increase in the 231,000 ha observed in the irrigated ecosystem in 1980-84 is expected (WARDA, 1993). Some African countries have large amounts of irrigated land planted to rice, especially Egypt, Niger, Mauritania with 100%, and Madagascar with 31% of its area irrigated (WARDA, 1993).

In the rain-fed lowland ecosystem**,** about one fourth of the world rice area from lowland, yields average about two tons per ha (Second G, 1997). Rain-fed lowlands have a great range of growing situations that differ by amount of rainfall and duration of rainfall, depth of standing water, duration of standing water, flooding frequency, and time of flooding, soil type and topography. In this ecosystem, the rice crops depend entirely on rainfall and do not receive irrigation (Bouman et al., 2007) mostly in tropical environment areas largely on flat land or mountain slopes. In this ecosystem, rice is planted under dry conditions just as wheat or maize (Dingkuhn, M. 1998). Rain-fed uplands accounts for 12% of global rice production area with low yielding (1.2 t ha^{-1}) compared to the other ecosystems due to rainfall distribution and variation in the upland rice fields (Dogara and Jumare, 2014). About 16 million hectares of world rice land is classified as upland (Dingkuhn, M. 1998).

Rice ecosystem, rice plants are grown in low lying lands in river deltas of South and Southeast Asia to a height of more than 50 cm during the entire rainy season (Bouman et al., 2007). Standing water depth may vary from 50 cm to more than 3m. Flooding occurs only during part of the growing season (Khush, 1997). The seeds are planted a few weeks earlier before the rain starts (Dogara and Jumara, 2014). In this ecosystem, the rice global production area accounts for 8% with a production of less than (2 t-ha). In Kenya, history has shown that irrigation has existed for many years along the lower reaches of River Tan and Keiyo, Marakwet, West Pokot and Baringo districts. Production under modern irrigation systems can be traced to the period after the introduction of cash crop farming such as coffee, pineapples, sisal and lucerne. The rain-fed cultivation is linked to the rainfall, the timing and duration of the cultivation cycle have adjusted accordingly, depending on the local soil conditions. Due to uncertain rainfall, risk aversion is a strong consideration in choice for rain-fed lowland rice. The unit yield of rain-fed rice production is slightly below two tons a hectare.

2.4. Rice Varieties Grown in Kenya

There are more than 1,200 varieties of rice under cultivation worldwide, and the differences in the varieties are related to the morphology of the plants and grains, resistance to biotic and biotic factors Li (2003). In Kenya, more than 15 cultivars of rice are grown in different geographical location within the country (Karlo, 2013), this includes Central, Nyanza, Western and coast. Table 2.1, shows irrigated cultivars grown in Kenya and their characteristics.

Table 2.1. Irrigated rice cultivars grown in Kenya and their characteristics.

Variety	Yield Potential	Description
BASMATI 217	4.5-5.5 ton ha^{-1} 1.8 – 2.2 tons/acre 23 -28 bags/acre	Aromatic, , tolerant to rice yellow mottle virus, and good cooking quality and Can be grown in irrigated ecologies in irrigated ecologies in Central, Nyanza, Western, Coast
BASMATI 370	4.5-5.5 ton ha^{-1} 1.8 – 2.2 tons/acre 23 -28 bags/acre	Aromatic, tolerant to rice yellow mottle virus, medium maturing and good cooking quality and Can be grown in irrigated ecologies in Central, Nyanza, Western, Coast
SINDANO	8 ton ha-1 3.2 ton/acre 40 bags/acre	Late maturing, poor cooking quality, susceptible to blast and rice yellow mottle virus. Can be grown in irrigated ecologies in Central, Nyanza, Western
IR2793-80-1	8.2 ton ha-1 3.3 ton/acre 41 bags/acre	Late maturing, good cooking quality, susceptible to blast and rice yellow mottle virus. Can be grown in irrigated ecologies in Central, Nyanza, Western, Coast
BW 196	8-10 ton ha-1 3.2 – 4 ton/acre 40 – 50 bags/acre	Resistant to blast, susceptible to rice yellow mottle virus, late maturing, medium cooking quality, and can be grown in irrigated ecologies in Central, Nyanza, Western, Coast
ITA 310	6-7 ton ha-1 2.4-2.8 tons/acre 30-35 bags/acre	Late maturing, good cooking quality, susceptible to blast and rice yellow mottle virus. Can be grown in irrigated ecologies in Central, Nyanza, Western, Coast
DOURADO PRECOCE	2.3-5.5 ton ha-1 0.9-2.2 ton/acre 12-28 bags/acre	Aweless, tolerant to Blast, Rice yellow mottle virus and Bacterial leaf blight, late maturing and good cooking quality. Can be grown in Upland ecologies in Western, Nyanza, Central

NAM ROO	5-7 ton ha-1 2-2.8ton/acre 25-35 bags/acre	Red stem, tall hence lodging, tolerant to Rice yellow mottle virus, late maturing. Can be grown in Upland ecologies in Coast, Nyanza, Central, Western
TGR -94	3-4 ton ha-1 1.2-1.6 ton/acre 15-20 bags/acre	Medium maturing, long grains and tolerant to blast. Can be grown in Upland ecologies in Coast, Nyanza, Central, Western
WAB 181-18	2.5-4 ton ha-1 1-1.6 ton/acre 13-20 bags/acre	Tolerant to blast, early maturing and good cooking quality. Can be grown in Upland ecologies in Nyanza and Western
NERICA 1	2.5-5 ton ha-1 1-2 ton/acre 12.5-25 bags/acre	Aromatic, Short awn, purple pigmentation on stem and grain, high protein content (25%), weed smothering ability, and tolerant to Blast, Rice yellow mottle virus and Bacterial leaf blight, early maturing and good cooking quality. Can be grown in Upland ecologies in Western, Nyanza, Rift Valley, Central, Eastern, N. Eastern, and Coast.
NERICA 4	3.2-6 ton ha-1 1.2-2.4 ton/acre 15-30 bags/acre	Long grain, high protein content, weed smothering, high tillering, medium threshability, and tolerant to Blast, Rice yellow mottle virus and Bacterial leaf blight, medium maturing and good cooking quality. Can be grown in Upland ecologies in Western, Nyanza, Rift Valley, Central, Eastern, N. Eastern, Coast
NERICA 10	3.5-6 ton ha-1 1.4- 2.4 ton/acre 18-30 bags/acre	Long grains, awned, purple pigmented grains, high protein content, tolerant to Blast, Rice yellow mottle virus and Bacterial leaf blight, early maturing and good cooking quality. Can be grown in Upland ecologies in Western, Nyanza, Rift Valley, Central, Eastern, N. Eastern, Coast
NERICA 11	3-5 tonha-1 1.2-2 ton/acre 15-25 bags/acre	Drought tolerant, high ratoonability, poor exertion, tolerant to pests & diseases, high protein content and tolerant to Blast, Rice yellow mottle virus and Bacterial leaf blight, medium maturing and good cooking quality. Can be grown in Upland ecologies in Western, Nyanza, Rift Valley, Central, Eastern, N. Eastern, Coast
WABIS-675	3-4 ton ha-1 1.2-1.6 ton/acre 15-20 bags/acre	Tolerant to blast and is medium maturing. Can be grown in lowland rain-fed ecologies in Coast, Nyanza, Central, Western

JASMINE-85	7-8 ton ha-1 2.8-3.2 ton/acre 35-40 bags/acre	Medium maturing, moderately susceptible to blast and good cooking quality. Can be grown in lowland rain-fed ecologies in Coast, Nyanza, Central, Western
TGR-78	4-5 ton ha-1 1.6-2 ton/acre 20-25 bags/acre	Long grains, medium maturing, tolerant to blast, good cooking quality and can be grown in lowland rain-fed ecologies in Coast, Nyanza, Central, Western

Source: www.karlo.org/ricebank

2.5. Grain Quality in Aromatic Rice

Aromatic rice has been introduced into global market, and utmost of the trade in aromatic rice is from India, Pakistan and Thailand. Aromatic rice from India and Thailand comprises of Basmati types, while Thailand is the source of Jasmine rice. Other key aromatic rice varieties in the world market are Khao Dawk Mali 105, Siamati (Thailand), Bahra (Afghanistan), Sadri (Iran), Della, Texami and Kasmati (USA) (Singh et al., 2000d).

Singh et al., (2000d) also cited that aromatic rice varieties which are popular in the world market are long grained, but majority of the Indian indigenous aromatic rice cultivars are small and medium grained. Large sums of land races of these varieties are originate in Himalayan Tarai of the state of Uttar Pradesh and Bihar of India, indicating that this region is probably the origin of aromatic rice.

Khus (2000) had grouped the aromatic cultivars into three groups: Group 1 (*Indica*), Group V1 (*japonica*) and Group V (which contains world famous high quality Basmati rice of India and Pakistan). Most of the aromatic rice cultivars come from Group V, in which the grains are long and medium in size such as Basmati, Kataribhog and Sadri, as well as cultivars with very small grains such as Nama Tha Lay. Simply a few aromatic cultivars belong to Group 1 (from Thailand, Vietnam, Cambodia and China).

Rice grain quality affects the commercial value of grains. Genotypes x Environment interaction factors influence rice quality. Grain quality, along with crop yield is an important criterion in most rice breeding programs especially in rice variety selection and development Dela et al., (2000). Rice is mainly determined by the combinations of many physical as well chemical characters. However, it is difficult to define grain quality because it involves objective and subjective criteria. According to Zhang and Yu (2000), cooking and eating quality are the most important components of rice quality. Based on Juliano (1991), country and culture results in different preferences for rice quality. For example, middle east consumers preferred long grain, well milled rice with strong aroma while European community generally prefers long grain rice with no scent because the present of any scent signals spoilage and contamination (Efferson, 1985). In West Africa, grain quality is based on the type of food people prepare for eating. Long grain and aromatic rice are used with sauce, short and medium grain rice is used in porridge mixed with sugar. Long grain aromatic rice has the greatest demand and is most expensive rice in local market. Although preference vary from one group of consumers to another, rice grains with a pleasant fragrance or aroma and soft texture usually achieve higher price in national and international markets (Nguyen and Bui, 2008).

Several researchers (Dela and Khus, 2000) concluded that grain quality is second after yield as the major rice breeding objectives as well other crop improvement. In future, grain quality will be even more important as very poor consumers, who depend largely on rice for their daily food, demand higher quality rice (Juliano and Villarreal, 1993).

According to Slaton et al. (2000) rice is marketed under three market types chosen as long-grain, medium-grain, and short-grain. Varieties of each grain type must follow within narrow limits to the size and shape specifications established for that type. Therefore, grain size and shape are among the first criteria of rice quality that breeders consider in developing new varieties for release in commercial production (Mutters, 1998). If the variety does not obey to recognized standards for grain size, shape, weight, and uniformity, it is simply not considered for release (Mutters, 1998). Quality of rice is not always easy to describe as it depends on the consumer and the intended end-use for the grain. Traditionally, plant breeders have focused on breeding for high yields and pest resistance. Recently the trend has changed to incorporating preferred quality features that increase the total economic value of rice (Dela and Khush, 2000). Rice grain quality is determined by its physical and chemical properties. Physical properties comprise kernel size, shape, milling recovery, degree of milling and grain appearance (Cruz and Khush, 2000). In rice, eating and cooking qualities are largely measured by the physical properties which greatly influence the consumer’s affinity (Rohilla, 2000).

Hammermeister (2008) suggested that knowing about grain quality starts with knowing the anatomy of a single grain, and that’s the key features of grain. Research from IRRI (2009) further showed that rice grain quality was not solely a varietal characteristic but also depended on the crop production environment, harvesting, processing and handling system.

Irshad (2001) categorized the quality characteristics in rice into 3 broad areas: (1) physical characteristics which include moisture content, shape, size, and milling (2) the analysis of physio-chemical characteristics of rice including amylose content, gel consistency, volume of expansion of cooked rice, and cooking time and (3) the organoleptic quality of cooked rice which include color, aroma, hardness, stickiness, and consistency.

Singh et al., (2000) concluded that grain quality is second only to yield as a key rice breeding objective. In the future, grain quality will be even added significant as very poor consumers, who depend largely on rice for their daily food, demand higher quality rice.

2.5.1. Grain dimension

The length and width of rice grain are important attributes that determine the classes of rice. Rice grain is objectively classified into three classes based on grain Length: Short, medium and long. In terms of width, the shape is determined by the ratio of two of the three dimensions length, width and the thickness. Richman et al. (2006) classified milled rice based on the length- width ratio as slender as long (>3.0), medium (> 2.1 < 3.0), short (> 1.1 <2.0) and round (< 1.1).

The length and width of the rice grains are variable, sometimes even within a variety, because of the variation in the length of the awn and the pedicel (IRRI, 2009). The size and shape is a stable varietal property that can be used to identify a variety (Rickman et al., 2006). Rice varieties are classified as short, medium, or long grain by rough kernel dimension ratio (Slaton et al., 2000). Length or size of rice grain is a measure of the rice kernel in its greatest dimension. They are categorized in four categories: (1) very long (more than 7.50 mm), (2) long (6.61- 7.50 mm), (3) medium (5.51- 6.60 mm), and (4) short (less than or equal to 5.50 mm). However, in Kenya the varieties vary from long grain, medium grain and short grain. Cultivars with long grains include Nerica 4, Nerica 10, TGR-78, Basmati 370 and Komboka.

2.5.2. Kernel Elongation

Linear elongation of kernel on cooking is one of the key features of fine or scented rice. Assessment of kernel appearance and its cooking quality form significant objectives in rice grain quality improvement programs. Grain size and shape mainly determine the market acceptability of rice, while cooking quality is influenced by the properties of starch. Certain varieties expand more in size than others upon cooking (Oko, 2012).

2.6. Genetic Improvement of Rice Cultivars

The genetic improvement is aimed at variability within and between a populations; it is a result of additive and non-additive gene effects. Genetic variability is the fundamental component for widening the gene pool in rice (Selvaraj et al., 2011).The genotypic coefficient of variations offers a measure to relate genetic variability present in various quantitative types (Akinwale et al., 2011). Success of breeding program is determined by the amount of genetic variability present in the population and the level to which the desirable traits are heritable. The magnitude of genetic variation varies with genotypes and environment, and is an essential element for selection and improvement of crop. The present of large amount of variability might be due diverse source of materials as well environmental influence affecting the phenotypes (Ovung et al., 2012).

Several studies have been conducted to examine the extent of genetic variability for yield and agronomic parameters in rice. (Ashfag et al., 2012) observed genetic variability in numerous rice traits and their link with yield. The results reported genetic variability in plant height, number of spike lets per panicle, panicle length, days to heading, and days to maturity and number of productive tillers per panicle. McCouch (2005) suggested that the use of readily available germplasm is an key strategy for incorporating genetic variability into rice breeding program, which can possibly create new cultivar with broadened genetic base and permit beneficial allelic combination.

Yadav et al., (2008) and Osman et al., (2012) reported that phenotypic coefficient of variation were slightly higher than the genotypic coefficients of variation for yield and its related traits studied in upland rice reflecting high genetic influence. The knowledge of genetic variability is for development of grain quality with high yielding varieties (Singh et al., 2011). According to Patel et al., (2012), significant genotype variation was reported for days to 50% flowering, plant height, panicle length, productive number of tillers and number of spikelet per panicle.

Analysis of genetic variability is a pre-requisite for initiating any crop improvement program and for adopting appropriate techniques (Babu et al., 2012). The extent of genetic variation in a population often relates to its breeding system. Genotypes which exhibit adequate genetic variations for main components are number of panicles; number of grains per panicle and grain weight is best option for improving grain yields (Xing and Zhang 2010).

2.7. General and Specific Combining ability Concepts

The ability of an inbred to transmit desirable performance to the hybrid progeny is referred to as combining ability and is very useful in isolation of desirable / acceptable lines and their evaluation in hybrid development (Fasahat et al., 2016). Combining ability is a general concept of classifying lines relative to their cross performance. The concept of combining ability was developed by Sprague and Tatum in (1942) through preliminary studies with maize and comprises of two parts (1) General Combining Ability (GCA), which is the average performance of a genotype in cross combinations involving a set of other genotypes, and is the result of additive gene action and (2) Specific Combining Ability (SCA), which is the expression of performance between any two inbred lines in relation to the average performance of all combinations and is the result of non-additive type of gene interaction.

This is one of the concepts that had been exploited to great extent by the plant breeders. Griffing (1956a) developed a model in which he proved that additive genetic variance involved in GCA variance while SCA variance resulted from dominant and epistasis components. Griffing (1956b) and Carnaham et al., (1960) suggested that GCA could include both additive as well as additive x additive interaction. Reddy (2002) studied on the basis of combining ability effects on five cross combinations which showed significant SCA effects for grain yield per plant, days to 50 % flowering, panicle length, number of productive tillers per plant, number of spikelets per panicle and 1000-grain weight and having one of the parent as good general combiner both under normal and late planting situation could be exploited in future breeding program to improve grain yield in lowland rice.

Sinha et al., (2006) studied combining ability for grain yield and its component traits in rice involving six parents in a set of diallel crosses in upland rice and reported that both GCA and SCA variances were highly significant for nine characters. However, the magnitude of GCA and SCA effects for days to flowering, plant height, panicle per plant, panicle length, panicle weight, grain per panicle and grain yield per plant indicated both additive as well as non-additive gene action were involved in the expression of the traits. Parihar and Pathak (2008) and reported high SCA effects for grain yield per plant had also desirable and significant SCA effects for other traits like panicle length, grains per panicle, and effective tillers per plant and 1000-grain weight.

Sharma and Mani (2008) studied combining ability analysis for grain yield and its components by using six Basmati lines with three testers and observed that the additive gene action was dominant for panicle length, grain yield and days to flowering further they reported that Kasturi and Haryana Basmati have good general combining ability for panicle length, days to flowering, grains per panicle and grain yield per plant whereas three crosses showed high SCA effect for panicle length and days to flowering and grains per panicle.

Li et al., (2010) studied the combining ability for yield and yield components characters with 9 male sterile lines and 8 restorer lines of Dian-type japonica hybrid rice widely used by the way of p x q incomplete diallel cross (NCD II) design. Both general combining ability (GCA) and the specific combining ability (SCA) of these characters were significant or highly significant. The grain weight of per plant, the spikelets of per panicle and the panicles of per plant were mainly affected by the non-additive effect, while the 1000-grain weight was mainly controlled by the additive effect while the filled spikelets of per panicle and the seed setting rate were controlled by both additive and non-additive effect. The other characters were influenced more greatly by restorer lines than by sterile lines, except the grain weight per plant, the spikelets per panicle and the seed setting rate. Several workers reported the nature of gene action through different biometrical methods in rice, which had been reviewed and the literature pertaining to combining ability is presented.

2.8. Mating designs in Rice

Mating design is the procedure of producing the progenies in plant breeding, theoretically and practically plant breeders and geneticists use different form of mating designs and arrangements for targeted purpose. Mating design was developed to estimate genetic variance, based on correlation between relatives and how they used to partition the variations into different genetic components. Mating designs play key roles in providing information on the genetics of the character under investigations, the designs also is use to generate a breeding population to be used as a basis for selection and development of potential varieties and to provide estimates of genetic gain by providing information for evaluating the parents used in the breeding program. Evaluation of the progenies in multi environments using appropriate experimental designs and statistical analyses provides good understanding of genotype, environment and genotype x environment interaction effects and reduces error. In addition, the additive model allows the estimation of components of variance.

Bi-parental mating design is also known as full-ship families, this design is one of the simplest design used for the estimation of genetic variance in a reference population as was termed Mather in 1949 (Aqcuaah, 2012). Bi-parental mating design involves pairs on individuals chosen randomly from a random population and mated. So this mating design gives information needed to determine whether the variation within a population is significant for long term selection program and also provides an opportunity for creating variability with minimum effort and cost (e.g., cross-pollinated species) (Hallauer et al., 2010).

Triple testcross mating design was developed by Kearsey and Jinks (1968). The design has the ability to detect epistatic effects (additive x additive, additive x dominance, dominance x dominance) for quantitative traits, and also gives estimates of additive and dominance genetic variances in the absence of epistasis (Kusterer et al., 2007). In triple testcross, random ample of male from F2 generation is obtain by crossing two inbred lines. The design is very effective for predicting the properties of recombinant inbred lines, understanding traits and their genetic correlations can help selection through recombination of favorable alleles and will improve genetic gains. Saleem et al., (2009) used triple test cross to study the genetic basis of seven agronomic traits in Basmati rice, thus Acquaah (2012) found that the design was capable of estimating dominance and additive variance as well as epistasis.

In North Carolina design I is suitable only for estimating genetic variance of a population which is assumed to be random and is linkage in equilibrium. Each male is crossed to a different set of females to produce progenies for evaluation. The genetic structure of the progenies will include full-sibs that have both parents in common and half-sibs that have a male parent in common (Acquaah, 2012).

North Carolina design II is very useful mating design; the design is also known as factorial design. Parents are divided into two groups of male and females. Each member of a group has equal chance to cross with a member from the other group (Bernardo et al., 2004). Although the assumptions for North Carolina design II are similar to North Carolina design I, North Carolina design II has greater precision, is more applicable to self-pollinated crops and has a direct estimate of the level of dominance. The number of crosses increases as the number of parents per group increases. If the number of experimental units is fixed, the number of parents used can be doubled in the experiment. This is an advantage of design II, and it allows for estimation of the genetic parameters of a reference population (Kearsey and Pooni, 1996).

North Carolina design III was developed to estimate the average level of dominance of genes affecting traits in pedigree breeding. The focus on expected mean squares is based on the component of variance among males and the one for the interaction of males and inbred parents. The design provides exact *F*-tests of two hypotheses concerning the relative importance of dominance effects (Hallerman et al., 1987). A reference population (F_2) is used to develop progenies by backcrossing randomly chosen males from the F_2 population to each of the parents (females) of the F_2. NC Design III is widely used in testing for presence of dominance effects, though linkage biases may affect the estimation of additive and dominance variance for the F_2 populations where effects of linkage are expected to be maximum (Cheng et al., 2008).

A complete diallel mating design first presented by Schmidt (1919) became an important tool used to produce crosses for evaluation of genetic variances. This mating design allows the parents to be crossed in all possible combinations (Schlegel, 2010), including selfs and reciprocals. Crosses are generated from parents ranging from inbred lines to broad genetic base varieties where progenies are developed from all possible combinations of parents involved (Hallauer et al., 2010). There are two models in this design, Model I is a fixed model based on the assumption that the parents used have undergone selection for a period of time and have become a complete population. The model measures only GCA and SCA effects because the parents are fixed. Model II is where parents are random taken from a random mating population.

The top cross was design to test inbred lines in cross-bred combinations. Top cross scheme is effective for testing big number of elite lines especially when crossed to a tester with wide or narrow genetic base. The cross is made between a plant of selected female and a common male tester of a known performance (variety, inbred line or single cross). However, top cross is mostly suitable for preliminary evaluation of combining ability of new inbred lines before pairing them into single cross hybrids (Abra, 2014). The parental pair-wise combinations are estimated based on: i) parental performance in pairwise combinations; ii) direct contribution of each parent to the progeny mean through additive gene action; and iii) reliability of the results being obtained is independent of the quantity of the data (Nduwumuremyi et al., 2013).

2.9. Heritability of yield and yield components in Rice

Heritability of a trait estimates the amount of the total phenotypic variation that is due to heritability (additive genetic) that is $VA/VP = h^2$. Heritability is a proportion of variability that can be passed on from parents to offspring; it is significant in defining cultivars responds to selection. Breeding for yield components to increase grain yields would be more effective if components involves are highly heritable and genetically independent (Akinwale et al., 2011). Thus the knowledge of heritability in the selection based improvement shows the transmissibility of character in future generations (Sabesan et al., 2009).

Selvaraj et al.,(2011) reported high heritability coupled with high genetic advance and high genotypic coefficient variations for number of productive tillers per plant, plant height and grain yield per plant. According to Panse (1957), if a character is governed by non-additive gene action, it may give high heritability but low genetic advance, whereas, if a character is governed by additive gene action, high heritability along with high genetic advance provide good range for further improvement.

The pertinent is to note that high heritability alone does not guarantee large gain from selection, unless sufficient genetic advance (GA) attributed to additive gene action (Tiawari et al., 2011; Akinwale et al., 2011).

2.10. Correlations among yield Components in Rice

Correlation analysis helps breeders the plant breeders to indirectly select for traits that influence yield and it provides an understanding of yield components (Golam et al., 2011). Correlation is an essential tool for plant breeders before embarking on any rice breeding program. Correlation indicates the magnitude of association between pairs of characters and forms the basis of selection index. Therefore, the knowledge of correlation studies in rice enables the plant breeder to understand how the improvement of one character brings a concurrent change in the other characters (Golam et al., 2011).

When two characters demonstrate negative phenotypic and genotypic correlations it would be difficult to exercise the selection for these characters (Newell and Eberhart, 1961). Yadav et al., (2011) reported that the negative correlation coefficient between plant height and paddy yield showed that tallness in rice reduces the paddy yield due to high accumulation of photosynthates in vegetative parts as compared to that in reproductive parts (i.e. seed formation and grain filling) and lodging susceptibility. Idris et al., (2012) shown that the genotypic correlation coefficients were higher than the phenotypic correlation coefficients indicating that, the observed relationships among the various characters were due to genetic causes. Broad knowledge on interrelationship of plant character like grain yield with other yield related characters is of greater significance to the breeder for making improvement in complex quantitative character like grain yield for which direct selection is not much effective.

CHAPTER THREE: EVALUATION OF RICE CULTIVARS FOR GRAIN YIELD, EARLINESS AND QUALITY TRAITS

3.0 Abstract

Improvement of grain yield is one of the major objectives in rice breeding program worldwide. Consumption of locally produced rice in eastern Africa is low because most smallholder farmers rely on local rice cultivars which have low yield potential, late maturing and poor cooking and eating qualities. As a result urban consumers prefer imported rice at the expense of the locally produced rice. However, the imported rice is expensive and unaffordable to the rural poor. Therefore, improving the grain yield, earliness and culinary qualities of the local cultivars will increase consumption of locally produced and affordable rice as well as its competitiveness in the local market. The objective of this study was to evaluate the $F_{2.3}$ families for yield potential, earliness and grain quality.

The study materials were F_2 populations developed between indica and japonica parents during the long rain season between March and June 2014 using a 6 x 6 half diallel mating design without reciprocals. The choice of the crosses was based on yield potential, grain quality traits and resistance to diseases The 14 F2 populations were evaluated at Mwea Research Station during the short rain season of 2016. Twelve data were collected on agronomic and yield traits and analyzed using Genstat 15th edition statistical software. The physical characteristics of the $F_{2.3}$ families were analyzed at the Mwea Research Station Laboratory.

The results showed significant ($P \leq 0.05$) genetic variation among the $F_{2.3}$ families for plant height flag leaf length number of tillers plant, number of spikelet's panicle and 1000 grain weight. Highly significant variation ($P \leq 0.001$) was observed for days to heading, days to 50% flowering ,days to maturity, number of filled grains panicle and grain yield.

The genotypes of NERICA 10, NERICA 1 and BASMATI 370 were relatively early maturing, exhibited short to intermediate plant height, while generations crosses of NERICA3 X BASMATI 370, NERICA2 x BASMATI 370 and BASMATI 370 consistently maintained high yields across the seasons.

The results of the physical analysis revealed that the $F_{2.3}$ families of NERICA 2 x BASMATI 370, NERICA 3 x BASMATI 370 and BASMATI 370 had high physical grain quality compared to non-Basmati rice cultivars.

3.1. Introduction

Food and Agricultural Organization (FAO) reported that the world rice requirement by 2050 will be 943.6 million tons which requires an annual increase of about 5.8 million tons from the present level of production. Annual rice production in Africa was estimated at 31 million t from 11 million hectares under cultivation (FAO, 2017). The annual demand and production of rice in Sub-Saharan Africa is estimated at 12 and 10.2 million t respectively while the annual population growth in the region is estimated at 2.6 % (FAO, 2017). The increasing demand of rice consumption in the Sub- Saharan Africa is attributed to rapid population growth, increasing urbanization as well as the relative ease of preservation and cooking (Macauley and Ramadjita, 2015). The African rice requirement by 2050 will be 99.2 million tons which requires an annual increase of about 0.1 % from the present level of production. Development of both lowland and upland rice cultivars with high yield potential and durable resistance to both biotic and abiotic stresses can contribute to the realization of this target (Dogara and Jumare, 2014).

Rice breeding focuses mainly on yield improvement, breeding for tolerance to biotic and abiotic stresses. However, little attempts have been made to breed for grain quality in Eastern Africa (Kimani, 2010). Rice consumers in eastern Africa prefer imported to locally produced rice. This is attributed to poor nutritional and cooking quality of the locally produced rice (Njiruh et al., 2013). The smallholder farmers grow traditional rice cultivars that have low yield potential, late maturing, highly susceptible to rice yellow mottle virus and rice blast. Grain quality of these landraces does not meet consumer preferences and market demand. Therefore, it is important to identify outstanding rice varieties through characterization of the available upland rice varieties which can be used directly to improve productivity and culinary quality of local rice cultivars grown by smallholder farmers.

Grain quality is one of the key parameters used by farmers while selecting for a suitable rice cultivar for commercial production. A preferred rice cultivar should not only have good agronomic performance but also high grain quality that is widely acceptable to farmers, millers and consumers. Consumer preference for rice is based on physical properties such as appearance after cooking and aroma, grain shape and grain size while the cooking and textural properties of the rice grain is dependent on chemical composition of the rice cultivar (Umadevi et al., 2010). Consumer preference for grain shape and size varies. Some consumers prefer short, bold grain while others prefer medium long grain (Dela Cruz and Khush, 2000), but long slender grain is preferred by consumers in Kenya (MoA, 2014).

In recent years, more scientists and breeders have focused on improving the quality of rice for different purposes and markets (Chen et al., 2012). Four main traits have been used to evaluate the quality of rice namely: milling properties, appearance, nutritional value, and cooking quality (Yu et al., 2008). Both the molecular genetic background and environment significantly affect the quality of rice (Adu-Kwarteng et al., 2003). Moreover, rice could also be considered as one of the best and cheapest alternative technology available to small-scale farmers for improving productivity of grain yields.

Therefore, to meet the fast growing demand for food and exploit untapped agricultural potentials, "New Rice for Africa" (NERICA) has recently been introduced and grown in different parts in Kenya (Zenna et al., 2008). However, few studies have been conducted to explain the relationship between the yield and quality of rice. .

3.2. Materials and Methods

3.2.1. Experimental Site

The experiment was performed at Kenya Agricultural Research and Livestock Organization (KARLO) Research center in Kirinyaga County, Kenya. The site lies on Latitude 00^o 37' S and Longitude 37^o 20' E at an elevation of 1159 m above sea level (masl). The average rainfall was about 850 mm with a range of 500 - 1250 mm divided into long rains (March - June with an average of 450 mm) and short rains (Mid-October to December with an average of 350 mm). The rainfall is characterized by uneven distribution in total amounts, time and space. The temperature ranges from 15.6^o C to 28.6^o C with a mean of about 22^{o}C.

The soil is a nitosol, which is deep, well drained dusky-red to dark reddish-brown, friable clay with low fertility (KARI, 2000).

3.2.2. Population generated and Germplasm Evaluated

The genotypes evaluated comprised of 7 parents and 7 F_2 populations (Table 3.1). The populations were developed in Mwea Research Station in 2014 using North Carolina 1 mating design without reciprocals, method four of Griffing, (1956). A total of 12 parents included in the crossing block of six male and six female in that order. The major aim of the crosses was to generate F_2 segregating populations for grain yield, grain quality, resistance to blast and drought tolerance.

Table 3.1. Rice genotypes grown in Kenya with different attributes screened for grain quality, earliness and yield.

Variety	Source/Origin	Variety type	Special Attributes
Basmati 370	India/Pakistan	Parent	Long slender grain, high yielding, superior aromatic rice with good cooking quality
Nerica 1	Africa Rice	Parent	High yielding potential, short growth cycle, perfume aroma with good cooking quality
Nerica 10	Africa Rice	Parent	high yield potential, short growth cycle, possess early vigor during the vegetative growth, good cooking quality, no aroma but smell at flowering stage
Dourado	Brazil	Parent	Aweless, tolerant to blast, rice yellow mottle virus and bacterial leaf blight, late maturing and good cooking quality.
Komboka	IRRI/Tanzania	Parent	High yielding, tolerant to most disease, mild aroma, local adapted cultivar with good grain quality but low yielding
Kuchum	KARLO-Mwea	Parent	high yield potential with good cooking quality
Mwur 4	KARLO-Mwea	Parent	Medium high yielding, drought tolerant, blast resistant
Dourado X Kuchum	KARLO-Mwea	$F_{2:3}$ progeny	Tolerance to blast and RYMV + high yielding with good cooking quality
K1-99 x Komboka	KARLO-Mwea	$F_{2:3}$ progeny	Drought tolerant + High yielding, tolerant to most disease, mild aroma, local adapted cultivar with good grain quality but low yielding
Nerica 10 X Kuchum	KARLO-Mwea	$F_{2:3}$ progeny	Early maturity, long grains and blast tolerant + High yielding potential with good cooking quality
Nerica 10 X Mwur 4	KARLO-Mwea	$F_{2:3}$ progeny	Early maturity, long grains and blast tolerant + High yielding
Nerica 2 X Basmati 370	KARLO-Mwea	$F_{2:3}$ progeny	Non aromatic and drought tolerant + Long slender grain, superior aromatic with good cooking quality
Nerica 3 X Basmati 370	KARLO-Mwea	$F_{2:3}$ progeny	Long slender grain, high yielding, superior aromatic rice with good cooking quality
Nerica 1 X Mwur 4	KARLO-Mwea	$F_{2:3}$ progeny	High yielding potential, short growth cycle, perfume aroma with good cooking quality + Medium yielding, drought tolerant and blast resistant

3.2.3. Design and crop husbandry

The materials were planted using a randomized complete block design with three replications at KALRO-Mwea experimental farm during (June-October) 2017. Each genotype was grown in a plot of 5 m by 5 m in size and in a row length of 3 m with inter and intra spacing of 20 cm with two seeds per hill. When the seedlings were 2-3 weeks old, gapping and thinning was carried out leaving one seedling per hill to ensure uniform plant density. Hand weeding was carried out at 20, 40 and 60 days after planting. Di-ammonium phosphate fertilizer (DAP) (18:46:0) was used as a source of P at a recommended rate of 60 kg P ha^{-1}. Sources of N were NPK (17:17:1) fertilizer was used at active tillering stage as a first top dressing and later Calcium Ammonium Nitrates (CAN) fertilizer was applied at panicle initiation stage at a rate of 47 kg N ha^{-1} . Pesticide (Duduthrin 1.75 EC, Lamba-cyhalothrim 17.5 g/L) was applied every two weeks to control stem borer, fall armyworm and leaf hoppers at a rate of 50 ml/20 L of water.

3.2.4. Agronomic Traits Studied

i. Days of 50% flowering were determined visually by counting the number of days from showing up to when 50% of the plants in each particular plot had flowered. The scale was 1 very early, 3 early, 5 medium and 7 late.
ii. Days to maturity was collected when 80% of the plants in a plot matured, the number of the date was counted from the date of sowing for each genotype in each replication and recorded.
iii. The height of the plant was measured (cm) from soil surface to tip of the tallest panicle (awns excluded) using a meter ruler. Whole numbers were recorded from two rows in the middle.
iv. Panicle length was measured at maturity stage from random selected plants; it was measured in centimeter from the basal node of the panicle to the tip of the panicle.
v. Numbers of Productive tillers was recorded by counting all the number of the panicle per plant from a sample of selected ten (10) plants per hill at emerging shoots.
vi. The fertile spikelet was determined as described by Laffite et al., (2003). Ten panicles were selected randomly from each plot. Spikelet fertility was scored as; 1 highly fertile (>90%), 3 fertile (75-89%), 5 partly sterile (50-74%), 7 highly sterile (<50% to trace), 9 completely sterile (0%).
vii. Number of grains per panicle was determined randomly from the selected panicles per plot, filled was separated using a seed separator method machine. The numbers of filled and unfilled (empty) grains were counted manually.
viii. One thousands seed weight (TGW) was obtained by individually counting 100 well developed whole grain. The samples were counted, dried to a moisture content of 14% and weighted using an electronic balance. The final weight was then converted to 1000 grain weight by multiplying by 10.

ix. Grain yield per plant was determined from 10 selected plants from each plot. The grain was harvested manually, hand threshed, and the grains dried to attain a moisture content of 14%. The moisture content was determined using a moisture meter. The grain was weighted in kg using machine balance. The mean grain weight obtained from the ten plants was calculated to give grain yield per plant in t/ha^{-1}.

3.3. Data Collection

Data on agronomic traits were collected according to the procedure outlined in Standard Evaluation System (SES) for rice (IRRI, 2013). Data were collected on days to maturity, plant height, panicle length, flag leaf, number of productive tillers, number of spikelet per panicle, number of filled grains, thousand grain weight and grain yield as indicated above:

3.3.1. Grain Quality

10 grains were counted at random from sample and measured at the respective dimensions using a vernier caliper (Rickman et al., 2006). The average of 10 grains was recorded. The scale by Vanangamudi et al., (1987) was used to classify seed length as: short (below 7.5mm), medium (7.5-9mm), long (9-10mm), very long (above 10mm) and grain width as slender (below 2mm), semi long (2-2.4mm), semi spherical (2.4-3mm), and spherical (above 3mm).

The dimensions of grain length and width were measured using vernier caliper. Ten grains from each variety were selected randomly and from the samples to determine their length and width (Rickman et al., 2006). The average of the length and width were measured based on the grains. The length of the grains was classified into four categories respectively: very long (>7.5mm), long (>6.6 <7.49mm), medium (>5.51 <6.6) and short (<5.5mm) (Rickman et al., 2006). According to length/width ratio, the grains were again classified into classes as slender (>3), medium (>2.1 <3), bold (>1.1 <2) and round (<1.1).

Sample of 2g milled rice kernels were measured from each of the rice samples and place in a petri-dish. The samples were soaked in 10 ml 1.7% KOH solution at room temperature for about 1 hour. Then a group of farmers and students was invited to score the soaked rice samples using a scale of 1- 4 scale. (1) No aroma, (2) Slight aroma, (3) Moderate aroma and (4) Strong aroma.

3.4. Data Analysis

The analysis of variance (ANOVA) to determine differences between genotypes was computed separately on individual experiments for all characters. This was done by GenStat 15th edition statistical package. The difference between treatments means and genotypes were separated using the least significant differences (LSD) test. Simple linear correlation was also done for the studied traits.

3.4.1. Estimation of variance components

The genotypic, environmental and phenotypic variances were estimated using the formula given by Singh and Chaudhuy (1999) as follows:

- Genotypic variance for individual analysis (Q^2g) = $\frac{MSG - MSE}{r}$
- For combined analysis of variance (Q^2g) = $\frac{MSG - MSE}{rS}$
- Phenotypic variance for individual analysis (Q^2p) = $Q^2g + \frac{Q2e}{r}$
- For combined analysis of variance (Q^2p) = $Q^2g + Q^2Gs + Q^2e$

Where,

MSG = mean square of genotype, MSE = mean square of error (environmental variance), r = the number of replications, S = number of Seasons Q^2e = random error, Q^2g = genotypic variance, and Q^2p = Phenotypic variance

3.4.2. Phenotypic and Genotypic coefficient of Variation

Based on the ANOVA, the phenotypic (PCV) and genotypic (GCV) coefficient of variation (individual and combine analysis) was estimated using the formula by Burton (1952) as follows:

$$GCV = \sqrt{Q2g}/x \times 100\ \%$$

$$PVC = \sqrt{Q2p}/x \times 100\ \%$$

Where; x = phenotypic trait population mean. GCV and PVC values will be considered as low (0 – 10%), moderate (10 – 20%) and high (more than or equal 20%) as suggested by Silvasubramian and Madhavamenon (1973).

3.4.3. Heritability (broad sense) Estimation

Broad sense heritability (H^2) was expressed as the percentage of the ratio of the genotypic variance (Q^2g) to the phenotypic variance (Q^2p) according to Allard (1960) as follows:

Broad sense heritability for individual analysis of variance:

$$(H^2) = \frac{Q2g}{Q2p} \text{ X } 100$$

$$(H^2) = Q2g/\ (Q^2g + Q2gL/r + Q2e/rs$$

Where; S, r and L are a number of seasons, replications and locations respectively. Heritability estimates will be categorized as low (0 – 30%), moderate (30 – 60%), high (≥ 60%). These values are recommended by Johnson et al., (1995).

3.4.4. Phenotypic Correlation

The phenotypic (p) correlation between two characters X and Y were calculated using the formula by Kwon and Torrie (1964):

$$P= \frac{COVp\ (X, Y)}{\sqrt{Vp\ (X).\ Vp\ (Y)}}$$

Where:

CovP (x, y) = Mean product of xy^{th} traits

VP(x) and VP(y) = Mean squares for x^{th} and y^{th} traits respectively:

3.5. Results

The analysis of variance results for the 14 genotypes studied revealed wide range of variability for most of the traits studied in both seasons and across the seasons (Table 3.2). The mean squares due to genotypes for all the traits were highly significant at levels ($P \leq 0.01$) and significant at ($P \leq 0.05$) except for panicle length across all the seasons, plant height and thousand grain weight in season two. Genotypes were significant at level ($P \leq 0.01$) for number of days to heading, days to 50% flowering, days to maturity, number of filled grain, number of empty (unfilled) grain and grain yield. Plant height, flag leaf, number of productive tillers, number of spikelet per plant and thousand grain weights were significant at level ($P \leq 0.05$) in both seasons. The combined analysis data due to genotypes showed highly significant at level ($P \leq 0.01$) for all traits except panicle length which was insignificant. Genotype x Season interactions were significant at level ($P \leq 0.01$) for all the traits studied except plant length and number of spikelet per plant, while plant height was significant at level ($P \leq 0.05$) (Table 3.2).

Table 3.2. Analysis of Variance for Agronomic Traits at Mwea Research Station Farm.

Source of V	Df	DH	DF (50%)	DM	PH	PL	FL	NPT	NSP	NFG	NEG	TGW	GY
						Season 1							
Rep	2	0.30	6.2	11.1	22.9	0.2	8.9	33.6	0.5	187.7	10.8	16.3	0.04
Genotype	13	118.8**	106.4**	163.0**	89.5*	3.9	7.6*	52.9*	5.7*	480.5**	106.2**	11.8*	3.2**
Residual	26	4.10	6.9	3.9	22.4	2.5	3.4	13	2.4	91.7	12.6	4.1	0.1
						Season 2							
Rep	2.0	4.0	3.4	8.7	52.9	0.2	3.9	3.2	5.8	113.2	18.7	2.8	0.6
Genotype	13.0	99.8**	65.2*	75.8**	37.1	3.7	20.2*	79.9**	14.38*	625.1**	74.7*	9.9	1.7**
Residual	26.0	3.7	17.5	4.0	36.5	3.4	7.5	11.1	4.5	72.5	34.5	3.4	0.2
						Across season							
Rep	2.0	2.8	2.1	13.3	52.5	0.3	12.1	12.2	3.3	284.5	28.9	10.1	0.3
Genotype	13.0	147.4**	119.4**	197.1**	65.1*	5.1	17.7**	113.0**	16.7**	814.7**	95.7**	13.2**	4.1**
Season	1.0	25.2*	45.8*	70.6**	434.8**	5.7	2.6	50.2*	22.4*	717.5	143.5*	1.2	1.5
Genotype * Season	13.0	71.2**	52.2**	41.8**	61.4*	2.5	10.178*	19.9	3.4	290.7**	85.3**	8.43*	0.8**
Residual	54.0	3.8	12.0	4.1	29.2	2.9	5.3	12.5	3.4	79.7	22.7	3.9	0.2

*, **, indicate significances at the 0.05, and 0.01 levels respectively. df, Degree of freedom; DH: Days to flowering; DF (50%): Days to 50 % flowering; DM: Days to Maturity; PH: plant height, PL: Panicle Length, FL: Flag leaf; NPT: Number of Productive Tillers per plant; NSP: Number of spikelet per plant; NFG: Number of Filled Grains per Plant, NEG: Number of empty grains per plant; TGW: 1000-grains weight (g), NT: Number of Tillers per plant, GY: grain yield (ta ha^{-1}).

3.5.1. Agronomic Performance of rice cultivars across Seasons

Days to maturity were highly significant at level ($P \leq 0.01$) in all the seasons throughout, genotype Nerica 1 was the first to mature among all the genotypes, while genotype (KI-99*Komboka) was late maturing in season 2016 (Table 3.3). In short rains season 2016, Nerica 10 displayed early maturity, while (Nerica 3 x Basmati 370) was late maturing (Table 3.4). Across the seasons, Nerica 10 consistently showed early, while Nerica 2 x Basmati 370 was late maturing genotype (Table 3.5).

Plant height showed differences among genotypes at the across seasons. Genotypes were significant different ($P \leq 0.01$) in short rains seasons of 2016 and across the season, while insignificant in longer rains season of 2017. Nerica 2 x Basmati 370 was the tallest while K1-99 x Komboka was the shortest genotype in long rain (Table 3.3). Combined analysis shown that Basmati 370 and Nerica 3 x Basmati 370 was the tallest in plant height while Nerica 1 x Mwur 4 was the shortest (Table 3.5).

Genotypes were insignificant for panicle length in short rains season of 2016, long rains seasons and across the seasons (Tables 3.3, 3.4 and 3.5).

The genotype with the longest flag leaf was Nerica3 x Basmati 370, while Basmati 370 had the shortest flag leaf in short rains season of 2016 (Table 3.3). Meanwhile in long rains season of 2017, K1-99 x Komboka displayed the longest flag leaf Nerica 10 had shortest flag leaf (Table 3.4). In both seasons, Nerica 10 x Kuchum recorded the longest flag leaf while Nerica 10 had few of the shortest flag leaf respectively (Table 3.5).

There was significant difference in the number of productive tillers in all the genotypes studied. In short rains season of 2016, genotype Nerica 3 x Basmati 370 had large numbers of tillers while KI-99 x Komboka had low numbers of tillers in (Table 3.3). Generation of Nerica 3 x Basmati 370 cross showed large number of productive tillers in long rains season of 2017 thus Nerica 1 with less numbers of productive tillers consistently in long rains season of 2017 and across the seasons (Tables 3.4 and 3.5).

The generation of crosses with the large number of spikelet per panicle was Dourado x Kuchum, while Nerica 10 x Kuchum gave small number of spikelets per panicle in short rains season of

2016 (Table 3.3). Nerica 10 was recorded with the large number of spikelet and genotype Kuchum had small number of spikelet consistently in short rain and across seasons (Tables 3.3 and 3.5).

Number of filled grains per panicle showed differences among genotypes in the two seasons. The generation of Nerica 3 x Basmati 370 cross consistently presented the highest number of filled grains per panicle in both seasons and across the seasons (Tables 3.3, 3.4 and 3.5), while Kuchum gave the lowest number of filled grain in short rains season of 2016 (Table 3.3), thus Nerica 1 gave lowest number of filled grain per panicle in long rains season of 2017 (Table 3.4). In all the seasons studied, genotype, Dourado was the least with number of filled grains (Table 3.5).

Differences among the genotypes were observed in 100 grain weight in all the seasons, the heaviest 1000 grain weight was recorded for Nerica 10 x Kuchum and the lightest was for Kuchum in short rains seasons of 2016 (Table 3.3). Genotype, Nerica 1 had the heaviest 1000 grain weight and Mwur 4 with the less thousand weight in long rains season of 2017 (Table 3.4). The combined analysis showed, generation of cross Nerica 3 x Basmati 370 had the heaviest 1000 grain weight while Dourado had the lightest number of 1000 grain weight (Table 3.5).

All genotypes gave different yield performances in both seasons. Generation cross of Nerica 3 x Basmati 370 had the highest grain yield in both seasons and across seasons (Tables 3.3, 3.4 and 3.5)~~.~~ Genotype, Dourado produced the lowest grain yield in short rains season of 2016 (Table 3.3), while Nerica 1 displayed lowest grain yield in long rains season of 2017 (Table 3.4). In combine analysis, Dourado recorded the lowest grain yield (Table 3.5).

Table 3.3. Performances of yield and its components for 14 genotypes studied at Mwea Research Centre short rains season, 2016.

Genotypes	DF (50%)	DM	PH	PL	FL	NPT	NSP	NFG	TGW	GY
Basmati 370 (Parent)	108.0	130.6	104.0	22.0	22.3	27.3	12.3	126.7	21.3	5.5
NERICA 1 (Parent)	117.6	128.6	95.3	20.7	26.3	21.7	11.6	120.7	24.6	3.8a
NERICA 10 (Parent)	104.6	126.6	96.0	24.0	23.6	23.7	15.3	117.7	20.4	3.6
DOURADO (Parent)	106.3	133.3	95.3	22.3	24.3	23.3	21.0	100.0	18.7	3.2
KOMBOKA (Parent)	109.0	132.0	95.1	21.7	25.3	25.0	10.7	118.7	22.5	4.2
KUCHUM (Parent)	106.6	135.6	99.0	21.3	23.6	21.7	11.6	99.0	18.9	4.0
MWUR 4 (Parent)	114.0	138.0	95.0	24.0	24.6	19.7	13.0	105.0	18.9	3.3
DOURADO x KUCHUM	113.3	135.6	101.0	23.4	26.0	23.0	27.7	118.3	20.3	4.2
K1-99 x KOMBOKA	127.3	152.0	91.6	21.3	24.0	17.7	23.3	118.3	20.1	3.9
NERICA 1 x MWUR 4	110.6	135.3	94.1	21.8	23.6	27.0	11.0	126.3	22.9	5.1
NERICA 10 x KUCHUM	111.3	134.6	103.2	23.0	26.3	26.7	9.6	133.3	24.9	4.9
NERICA 10 x MWUR 4	107.6	131.0	97.6	23.7	26.0	23.0	11.3	123.7	20.3	5.0
NERICA 2 x Basmati370	105.7	149.0	109.6	21.3	25.0a	32.0	11.0	134.7	22.1	6.0
NERICA 3 XBasmati370	112.3	143.0	108.0	23.7	28.3	34.3	11.7	142.7	21.9	6.7
Grand mean	**111.1**	**136.1**	**98.9**	**22.4**	**24.9**	**25.3**	**11.6**	**120.4**	**21.3**	**4.5**
S.E±	**2.1****	**1.6****	**3.8***	**1.2 n.s**	**1.5***	**2.9***	**1.2***	**7.8***	**1.7***	**0.3****
LSD 5%	**4.4**	**3.3**	**7.9**	**2.7**	**3.1**	**6.0**	**2.6**	**16.0**	**3.4**	**0.6**
CV%	**2.4**	**1.5**	**4.8**	**7.1**	**7.4**	**14.3**	**13.5**	**8.0**	**9.5**	**8.1**

Key: **: significant at level ($P \leq 0.01$), *:significant at level ($P \leq 0.05$), n.s: not significant DF (50%): Days to 50 % flowering; DM: Days to Maturity; PH: plant height (cm), PL: Panicle Length(cm), FL: Flag leaf(cm); NPT: Number of Productive Tillers per plant; NSP: Number of spikelet per plant; NFG: Number of Filled Grains per Plant, NEG: Number of empty grains per plant; TGW: 1000-grains weight(g), NPT: Number of Productive tillers per plant, , GY: grain yield (ta ha^{-1}):.

Table 3.4. Performances of yield and its components for 14 genotypes studied at Mwea Research Centre long rains season, 2017.

Genotypes	DF (50%)	DM	PH	PL	FL	NPT	NSP	NFG	TGW	GY
Basmati 370 (Parent)	111.7	131.3	100.2	24.8	21.5	28.0	9.7	124.3	20.6	5.2
NERICA 1 (Parent)	115.0	132.0	90.8	21.8	27.8	15.3	10.3	86.3	22.8	3.5
NERICA 10 (Parent)	109.7	127.7	98.0	23.3	20.7	25.3	17.0	121.3	21.3	4.9
DOURADO (Parent)	104.7	130.3	92.7	21.2	25.0	18.6	10.3	96.7	19.3	4.0
KOMBOKA (Parent)	115.3	131.7	92.3	23.0	21.1	18.7	10.0	105.3	22.7	4.3
KUCHUM (Parent)	103.0	137.3	93.7	22.7	25.3	22.3	7.3	110.3	19.6	4.6
MWUR 4 (Parent)	114.7	138.3	97.3	24.1	26.3	24.7	12.8	125.3	21.8	5.4
DOURADO x KUCHUM	107.7	131.7	93.0	21.5	23.3	19.0	10.0	102.7	18.6	4.2
K1-99 x KOMBOKA	112.3	145.0	94.8	22.8	28.9	20.5	9.7	103.8	21.4	4.1
NERICA 1 x MWUR 4	106.7	132.0	89.9	21.8	22.5	28.3	9.1	127.7	19.4	5.3
NERICA 10 x KUCHUM	101.7	132.3	97.7	24.3	28.0	21.7	10.7	110.0	20.3	4.5
NERICA 10 x MWUR 4	109.3	134.6	96.9	23.8	24.9	26.3	10.9	122.3	22.2	5.2
NERICA 2 x Basmati370	107.0	132.3	87.9	23.2	25.1	30.7	10.0	132.0	19.4	5.9
NERICA 3 XBasmati370	115.3	143.7	96.2	23.2	23.7	33.0	9.7	135.0	25.2	6.0
Grand mean	**109.6**	**134.3**	**94.4**	**23.0**	**24.6**	**23.7**	**10.5**	**114.5**	**21.0**	**4.8**
S.E±	**3.4***	**1.6****	**4.9 n.s**	**1.5**	**2.2***	**2.7****	**1.7***	**6.9****	**1.5 n.s**	**0.4****
LSD 5%	**7.0**	**3.4**	**10.1**	**3.1**	**4.6**	**5.5**	**3.6**	**14.3**	**3.1**	**0.8**
CV%	**3.8**	**1.5**	**6.4**	**8.1**	**11.2**	**14.0**	**20.1**	**7.4**	**8.7**	**10.2**

Key: **: significant at level ($P \leq 0.01$), *:significant at level ($P \leq 0.05$), n.s: not significant DF 50%: Days to 50 % flowering; DM: Days to Maturity; PH: plant height (cm), PL: Panicle Length(cm), FL: Flag leaf(cm); NPT: Number of Productive Tillers per plant; NSP: Number of spikelet per plant; NFG: Number of Filled Grains per Plant, NEG: Number of empty grains per plant; TGW: 1000-grains weight(g), NPT: Number of Productive tillers per plant, , GY: grain yield (ta ha^{-1}):.

Table 3.5. Performances of yield and its components for 14 genotypes studied at Mwea Research Centre for Combined rains seasons of 2016/2017.

Genotypes	DF (50%)	DM	PH	PL	FL	NPT	NSP	NFG	TGW	GY
Basmati 370 (Parent)	109.8	131.0	102.1	23.4	21.9	27.7	11.0	125.5	20.9	5.4
NERICA 1 (Parent)	116.3	130.3	93.0	21.2	27.1	18.5	11.0	103.5	23.7	3.7
NERICA 10 (Parent)	107.2	127.2	97.0a	23.7	21.8	24.5	16.2	119.5	20.9	4.3
DOURADO (Parent)	105.5	131.8	94.0	21.8	24.7	19.8	11.0	98.3	19.0	3.6
KOMBOKA (Parent)	112.2	131.8	93.8	22.3	23.2	21.8	10.3	112.0	22.6	4.2
KUCHUM (Parent)	104.8	136.5	96.3	22.0	24.5	22.0	9.5	104.7	19.3	4.3
MWUR 4 (Parent)	114.3	138.2	96.2	24.0	25.5	22.2	12.9	115.2	20.4	4.3
DOURADO x KUCHUM	110.5	133.7	97.0	22.5	24.7	23.3	10.0	110.5	19.5	4.2
K1-99 x KOMBOKA	119.8	148.5	93.2	22.1	26.4	21.9	10.4	111.1	20.8	4.0
NERICA 1 x MWUR 4	108.7	133.7	92.0	21.8	23.1	27.7	10.1	127.0	21.2	5.2
NERICA 10 x KUCHUM	106.5	133.5	100.4	23.7	27.2	22.3	10.2	121.7	22.6	4.7
NERICA 10 x MWUR 4	108.5	132.8	97.3	23.8	25.5	26.5	11.1	123.0	21.2	5.1
NERICA 2 x Basmati370	106.3	140.8	98.8	22.3	25.1	31.3	10.5	133.3	20.8	5.9
NERICA 3 XBasmati370	113.8	143.3	102.1	23.5	26.0	33.7	10.7	138.8	23.6	6.4
Grand mean	**110.3**	**135.2**	**96.7**	**22.7**	**24.8**	**24.5**	**11.1**	**117.4**	**21.2**	**4.7**
S.E±	**2.8****	**1.6****	**4.4***	**1.4 n.s**	**1.9***	**2.9****	**1.5***	**7.3****	**1.6***	**0.4****
LSD 5%	**5.7**	**3.3**	**8.9**	**2.8**	**3.8**	**5.9**	**3.0**	**14.6**	**3.2**	**0.7**
CV%	**3.1**	**1.5**	**5.6**	**7.4**	**9.3**	**14.4**	**16.8**	**7.6**	**9.4**	**9.5**

Key: **: significant at level ($P \leq 0.01$), *:significant at level ($P \leq 0.05$), n.s: not significant DF 50%: Days to 50 % flowering; DM: Days to Maturity; PH: plant height (cm), PL: Panicle Length(cm), FL: Flag leaf(cm); NPT: Number of Productive Tillers per plant; NSP: Number of spikelet per plant; NFG: Number of Filled Grains per Plant, NEG: Number of empty grains per plant; TGW: 1000-grains weight(g), NPT: Number of Productive tillers per plant, , GY: grain yield (ta ha^{-1}):.

3.5.2. Phenotypic Correlations

Phenotypic correlation coefficients for yield and yield components at Mwea Research center for short rains season of 2016 are presented in (Table 3.6). In short rains season of 2016, days to 50% flowering was positive correlated with days to heading (r = 0.86), and days to maturity shows significant positive association with days to heading (r = 0.37) and days to 50% flowering (r = 0.48). Positive correlation were observed between flag leaf and days to heading at (r = 0.29), and number of productive tillers with plant height (r = 0.59), number of filled grains was positively correlated with panicle height (r = 0.38) and number of productive tillers (r = 0.59), and number of unfilled grain was negatively correlated with plant height (r = 0.47). Thousands grain weight was positively associated with number of productive tillers at (r = 0.28). Grain yield was positively correlated with plant height (r = 0.63), number of productive tillers (r = 0.78), number of filled grains (r = 0.79) and thousands grain weight at (r = 0.33) (Table 3.6).

In long rains season of 2017, the highest phenotypic correlation was shown between 50% days to flowering at (r = 0.56) and days to maturity at (r = 0.56) and 50% days to flowering at (r = 0.29) (Table 3.7). Panicle length was positively correlated with plant height at (r = 0.31), and flag leaf was positively in association with days to maturity at (r = 0.38). 1000 grain weight was positively correlated relationship with days to heading (r = 0.38), days to 50% flowering (r = 0.43) and days to maturity at (r = 0.28). Grain yield was positively correlated with number of productive tillers (r = 0.90), number of filled grains (r = 0.93), and inversely correlated with number of empty grains per panicle at (r = 0.49). On the other hand, number of empty grains was negatively correlated with days to heading (r = 0.29), days to maturity (r = 0.32), plant height (r =0.34) and number of productive tillers at (r = 0.42) respectively (Table 3.7).

Phenotypic correlation across seasons is shown in (Table 3.8). In the combined analysis, 50% days to flowering were strong positively correlated to days to heading at (r = 0.76). Days to maturity was strongly correlated with days to heading at (r = 0.45). Plant height was positively correlated with days to maturity at (r = 0.24) and days to 50% flowering at (r = 0.41), and flag leaf was positively associated with days to heading (r = 0.27), and days to maturity at (r = 0.24) respectively. Similarly number of productive tillers was positively correlated with days to maturity at (r = 0.23) and plant height at (0.37), and number of filled grains also positively correlated with number of productive tillers at (r = 0.76). On the contrary, number of empty grains was negatively correlated with number of productive tillers (r = 0.4) and number of filled grains at (r = 0.41). 1000 grain weight was positively associated with days to heading at (r = 0.20), days to 50% flowering (r = 0.24), number of productive tillers (r = 0.26), number of filled grains (r = 0.32) and inversely correlated to number of empty grain at (r =0.2) respectively. Thus, grain yield was positively correlated with days to maturity at (r = 0.21), plant height (r = 0.32), and highly associated with number of productive tillers (r =0.79), number of filled grains (r = 0.80), thousand grain weight (r =0.27) and strongly negatively correlated with number of empty grains per plant.

Table 3.6. Phenotypic correlation coefficients among agronomic traits in short rains season of 2016.

	DH	DF (50%)	DM	PH	PL	FL	NPT	NSP	NFG	NEG	TGW	GY
DH	-											
DF (50%)	0.86**	-										
DM	0.37*	0.48*	-									
PH	-0.29*	-0.29*	0.23	-								
PL	-0.01	-0.2	-0.13	0.17	-							
FL	0.29*	0.18	0.12	0.16	0.18	-						
NPT	-0.19	-0.12	0.29	0.59**	0.01	0.19	-					
NSP	-0.24	-0.18	-0.25	-0.17	0.26	-0.13	-0.10	-				
NFG	0.02	0.03	0.18	0.38*	0.06	0.37	0.59**	-0.08	-			
NEG	0.15	0.24	0.07	-0.47*	0.02	-0.24	-0.47	0.29*	-0.56**	-		
TGW	0.06	0.07	-0.18	0.18	-0.15	0.29	0.28*	-0.24	0.50**	-0.33	-	
GY	-0.22	-0.17	0.30	0.63**	0.02	0.29	0.78**	-0.16	0.79**	-0.58**	0.33**	-

* Significance at the 0.05 level, and ** significant at 0.01 level respectively. DH: Days to heading, DF (50%): Days to 50 % flowering; DM: Days to Maturity; PH (cm): plant height , PL (cm): Panicle Length , FL (cm): Flag leaf; NPT: Number of Productive Tillers per plant; NSP: Number of spikelet per plant; NFG: Number of Filled Grains per Plant, NEG: Number of empty grains per plant; TGW (g): 1000-grains weight (g), GY (t ha^{-1}): grain yield

Table 3.7. Phenotypic correlation coefficients among agronomic traits in long rains rice season of 2017.

	DH	DF (50%)	DM	PH	PL	FL	NPT	NSP	NFG	NEG	TGW	GY
DH	-											
DF (50%)	0.56**	-										
DM	0.56**	0.29**	-									
PH	0.26	-0.02	0.18	-								
PL	0.21	0.14	0.13	0.31*	-							
FL	0.25	-0.05	0.38*	-0.10	0.28	-						
NPT	0.17	-0.09	0.13	0.10	0.21	-0.26	-					
NSP	0.09	0.09	-0.28	0.03	0.18	0.06	-0.05	-				
NFG	0.16	0.02	0.12	0.07	0.24	-0.36	0.89**	-0.03	-			
NEG	-0.29*	-0.23	-0.32*	-0.34*	-0.11	0.04	-0.42*	0.26	-0.39*	-		
TGW	0.38*	0.43*	0.28*	0.08	0.16	0.06	0.23	0.09	0.12	-0.10	-	
GY	0.18	0.12	0.12	0.08	0.23	-0.34	0.90**	-0.09	0.93**	-0.49**	0.21	-

* Significance at the 0.05 level, and ** significant at 0.01 level respectively. DH, Days to heading; DF (50%): Days to 50 % flowering; DM: Days to Maturity; PH (cm): plant height , PL (cm): Panicle Length , FL (cm): Flag leaf; NPT: Number of Productive Tillers per plant; NSP: Number of spikelet per plant; NFG: Number of Filled Grains per Plant, NEG: Number of empty grains per plant; TGW (g): 1000-grains weight (g), GY (t ha^{-1}): grain yield

Table 3.8. Combined analysis of phenotypic correlation coefficients among agronomic traits across the two seasons.

	DH	DF (50%)	DM	PH	PL	FL	NPT	NSP	NFG	NEG	TGW	GY
DH	-											
DF (50%)	0.76**	-										
DM	0.45**	0.41**	-									
PH	-0.02	-0.11	0.24*	-								
PL	0.08	-0.04	-0.03	0.18	-							
FL	0.27*	0.05	0.24*	0.03	0.22*	-						
NPT	0.04	-0.07	0.23*	0.37**	0.09	-0.08	-					
NSP	-0.02	0.06	-0.21	0.03	0.17	-0.02	-0.03	-				
NFG	0.10	0.05	0.18	0.27	0.12	-0.07	0.76**	-0.07	-			
NEG	-0.05	0.04	-0.06	-0.31	-0.07	-0.05	-0.4**	0.30*	-0.41**	-		
TGW	0.20*	0.24*	0.04	0.15	-0.07	0.16	0.26*	-0.04	0.32*	-0.21*	-	
GY	-0.06	-0.06	0.21*	0.32*	0.14	-0.07	0.79**	-0.15	0.80**	-0.55**	0.27*	-

* Significance at the 0.05 level, and ** significant at 0.01 level respectively. DH, Days to heading; DF (50%): Days to 50 % flowering; DM: Days to Maturity; PH (cm): plant height , PL (cm): Panicle Length , FL (cm): Flag leaf; NPT: Number of Productive Tillers per plant; NSP: Number of spikelet per plant; NFG: Number of Filled Grains per Plant, NEG: Number of empty grains per plant; TGW (g): 1000-grains weight (g), GY (t ha^{-1}): grain yield

3.5.3. Grain Quality Performance

Among the genotypes studied, the length/width (L/W) ratio ranged from 0.73 to 3.08 mm. Genotype with the highest L/W ratio was Nerica 10*Mwur 4 (3.08 mm), and the one with lowest was for Nerica 10 (0.73 mm). Based on the L/W, the collected rice varieties were classified into different categories: long medium, long bold, intermediate medium, very long slender and very long medium grains (Table 3.9).

Aroma was detected in most of the genotypes studied; the strong aroma was detected in Basmati 370, while genotypes with moderate aroma were Nerica 1, Nerica 2*Basmati 370 and Nerica 3*Basmati 370. Genotypes with no aroma at all were Nerica 10 and K1-99*Komboka.

Table 3.9. Mean Performance of Grain Quality traits among the rice genotypes

Genotype	GL	GW	L/W	Grain Category	Grain Shape	Aroma
Basmati 370 (Parent)	7.5	2.6	2.9	Long	Medium	Strong Aroma
NERICA 1 (Parent)	6.8	2.4	2.8	Long	Medium	Moderate Aroma
NERCA 10 (Parent)	6.9	2.5	2.7	Long	Medium	No Aroma
DOURADO (Parent)	6.1	2.5	2.4	Intermediate	Medium	Slight Aroma
KOMBOKA (Parent)	7.0	2.6	2.7	Long	Medium	Slight Aroma
KUCHUM (Parent)	6.1	2.4	2.6	Intermediate	Medium	Slight Aroma
MWUR 4 (Parent)	6.3	2.4	2.7	Intermediate	Medium	Slight Aroma
DOURADO * KUCHUM	6.2	2.5	2.5	Intermediate	Medium	Slight Aroma
K1-99 * KOMBOKA	6.5	2.4	2.7	Intermediate	Medium	No Aroma
NERICA 1 * MWUR 4	7.3	2.4	3.0	Long	Slender	Slight Aroma
NERICA 10 * KUCHUM	6.8	2.6	2.6	Long	Medium	Slight Aroma
NERICA 10 * MWUR 4	7.8	2.5	3.1	Very long	Slender	Slight Aroma
NERICA 2 * Basmati 370	7.5	2.9	2.5	Long	Medium	Moderate Aroma
NERICA 3 * Basmati 370	8.6	3.2c	2.7	Very long	Medium	Moderate Aroma
Grand mean	**6.95**	**2.57**	**2.7**			
S.E±	**0.2****	**0.1****	**0.08****			
LSD 5%	**0.36**	**0.243**	**0.163**			
CV%	**3.1**	**5.6**	**3.6**			

3.5.4. Estimation of Mean, genotypic, phenotypic and environmental variance 2016/2017.

Table 3.10 shows the genotypic, phenotypic and environment variance for short rains season of 2016 and long rains season of 2017 in Mwea research center. The average means evaluated varied from 4.50 for grain yield to 136 for days to maturity in short rains season of 2016 and from 4.80 for grain yield to 134 for days to maturity in season 2017 (Table 3.10). Mean squares fluctuated from 3.23 for grain yield to 346 for number of filled grain in short rains season of 2016 and from 1.65 for grain yield to 577 for number of filled grain. Environmental variance in short rains season of 2016 ranged from 0.14 to 425 for grain yield, but in long rains season of 2017, environmental variances varied from 0.24 to 405 for number of filled grain. Likewise, genotypic variance ranged from 1.03 to 38.23 in days of heading in short rains season of 2016 and 0.47 to 57.33 in number of filled grain in long rains season of 2017. Phenotypic variance displayed the range from 1.08 to 115.53 in number of field grain in short rains season of 2016 and from 0.55 to 192.33 in number of filled grain respectively Table 3.10.

Table 3.10. Estimate of environment, genotype and phenotypic variance for 14 traits evaluated at Mwea for short rains season 2016 and long rains season 2017.

	Mean		Mean squares		Q2e		Q2g		Q2p	
Traits	Season 2016	Season 2017	Season 2016	Season 2017	Season 2016	Season 2017	Season 2016	Season 2017	Season 2016	Season 2017
DH	96.2	95.1	118.8	99.8	4.07	3.72	38.2	32.0	39.6	33.3
D50%F	111.1	109.6	106.4	65.2	6.88	17.48	33.2	15.9	35.5	21.7
DM	136.1	134.3	163.0	75.8	3.91	4.00	53.0	23.9	54.3	25.3
PH	98.9	94.4	89.5	37.1	22.43	36.46	22.4	0.2	29.8	12.4
PL	22.4	23.0	3.9	3.7	2.5	3.42	0.5	0.1	1.3	1.2
FL	24.9	24.6	7.6	20.2	3.396	7.52	1.4	4.2	2.5	6.7
NT	25.3	23.7	52.9	79.9	13.03	11.09	13.3	22.9	17.6	26.6
NSP	11.6	10.5	5.7	14.4	2.423	4.47	1.1	3.3	1.9	4.8
FGP	120.4	114.5	480.5	625.1	91.69	72.48	129.6	184.2	160.2	208.4
EGP	18.6	16.0	106.2	74.7	12.58	34.53	31.2	13.4	35.4	24.9
TGW	21.3	21.0	11.8	9.9	4.103	3.36	2.6	2.2	3.9	3.3
GYP	4.5	4.8	3.2	1.7	0.1353	0.24	1.0	0.5	1.1	0.6

Q^2 e = environment variance, Q^2 g = genotypic variance, Q^2 p = phenotypic variance, DH = Days to heading, DF 50% = Days to 50% flowering, DM = Days to maturity, PH (cm) = plant height, PL (cm) = panicle length, FL (cm) flag leaf, NPT = Number of productive tillers, NSP = Number of spikelet per plot, NFG = Number of filled grain, NEG = Number of empty grain, TGW (g) = 1000 grains weight, GY (t ha^{-1}) = Grain yield.

3.5.5. Genotypic coefficient of variation, phenotypic coefficient of variation and broad sense heritability.

The highest GVC values were recorded for grain yield in season and followed by number of empty grain in long rain (22.57 and 18.82). In short rains season of 2016, the highest figure was shown in number of empty grain followed by number of spikelet (20.40 and 17.31).The highest PVC was revealed for number of empty grain and grain yield in short rains season of 2016 (23.27 and 23.06). In long rains season of 2017, the highest figure was revealed in number of empty grain followed by number of spikelet (28.08 and 20.85) respectively (Table 3.11). The heritability estimates were high in short rains season of 2016 for most of the traits; DH (96.57 short rains season of 2016; 96.28 long rains season of 2017), days to 50% flowering (93.53 short rains season of 2016; 73.17 long rains season of 2017), days to maturity (97.60 short rains season of 2016; 94.73 long rains season of 2017), plant height (74.93 short rains season of 2016: 68.7 long rains season of 2017),panicle length (35.9 short rains season of 2016: 30.5 long rains season of 2017), flag leaf (62.83 short rains season of 2016), number of empty grain (65.36), thousand grain weight (64.99 short rains season of 2016; 66.04 long rains season of 2017)and grain yield (95.81 short rains season of 2016; 85.41 long rains season of 2017) (Table 3.11).

Table 3.11. Coefficients of genotypic and phenotypic variations and heritability for 14 traits of rice at Mwea for short rains season of 2016 and long rains season of 2017.

	GCV%		PCV%		H_2%	
Traits	Season 2016	Season 2017	Season 2016	Season 2017	Season 2016	Season 2017
DH	6.4	6.0	6.5	6.1	96.6	96.3
DF (50%)	5.2	3.6	5.4	4.3	93.5	73.2
DM	5.3	3.6	5.4	3.7	97.6	94.7
PH	4.8	3.5	5.5	3.7	74.9	68.7
PL	3.0	1.3	5.1	4.8	35.9	30.5
FL	4.7	8.4	6.4	10.5	55.3	62.8
NPT	14.4	20.2	16.6	21.7	75.4	86.1
NSP	9.0	17.3	11.9	20.9	57.5	68.9
NFG	9.5	11.9	10.5	12.6	80.9	88.4
NEG	30.0	22.9	31.9	31.2	88.2	53.8
TGW	7.5	7.0	9.3	8.6	65.2	66.1
GYP	22.5	14.5	23.0	15.7	95.8	85.8

GCV % = genotypic coefficient of variation, PCV % = phenotypic coefficient of variation, H_2 % = broad sense heritability, GAM = genetic advance as % of mean, DH = Days to heading, DF 50% = Days to 50% flowering, DM = Days to maturity, PH (cm) = plant height, PL (cm) = panicle length, FL (cm) flag leaf, NPT = Number of productive tillers, NSP = Number of spikelet per plot, NFG = Number of filled grain, NEG = Number of empty grain, TGW (g) = 1000 grains weight, GY (t ha^{-1}) = Grain yield.

3.6. Discussion

The separation of genotypes, environment and their interactions provide a good understanding of different cultivar across the seasons. Genotype x environment (season) interactions showed significant ($P \leq 0.01$ and $P \leq 0.05$) differences for most of the traits studied revealing that genotypes reacted differently for these traits at the two seasons (Table 3.3 and 3.4). Therefore, this could explain the genetic variation which was observed in the material tested. According to (Ovung et al., 2012), the presence of larger amount of genetic variation might be due to diverse source of materials as well as environmental influence. Thus similar genetic variations have been reported by (Akinwale et al., 2011) and (Singh et al., 2011) who observed significant genotypic variation for all characters studied in rice.

Genotypes showed wide range of genetic variability in relation to days to flowering from 106 to 119 days (Table 3.5). The variation in rainfall distribution prior to flowering could be the cause of that delay. Days to 50% flowering is controlled by both genetic factors and environmental conditions (Sabouri and Nahvi, 2009). Genotypes Nerica 2 x Basmati 370, Basmati 370, Dourado and Nerica 10 had relatively short duration to flowering implying these varieties allow farmers to increase cropping from two to three crops of rice per year.

Occurrence of early maturing was not only vital for rice crop improvement but also for climate alleviation for areas with marginal rainfall pattern. Difference among genotypes for days to flowering, mainly the medium and late flowering genotypes could be real criteria for areas with bimodal rainfall, and late flowering genotypes can be useful if genotypes flower near the end of rain season when moisture is adequate (Kihupi, 1984).

Across the seasons, there was variation in panicle length (Table 3.5). The genotypes, Basmati 370 and Nerica 10 x Kuchum had the longest panicle while Dourado and Dourado x Kuchum had the shortest panicle. The variation in panicle length across the seasons could be due to high vegetative growth observed at Mwea Research Station due to regular irrigation of the trial. The panicle length of rice plant determines the number of grains to be accommodated. The results also revealed that genotypes with long panicles contained more grains than short panicle genotypes. Similar results was reported by Efisue et al., (2014) who observed high grain yields in rice genotypes IRBW-123 that exhibited longer panicles.

Generation of crosses of Nerica 10 x Kuchum and Nerica 1 had the longest flag leaves while Komboka and Basmati 370 had the shortest flag leaf length (Table 3.5). The variation in flag leaf length across the rains could have been due to vegetative growth. Rice plants with long flag leaf have large surface area to intercept sun light and they can undertake more photosynthetic activities thus generating more assimilates for grain filling leading to heavier grain weight and higher grain yield. This study is in agreement with Bharali and Chandra (1994) who reported a higher direct effect of flag leaf area on grain yield.

There was variation in number of tillers across the rainy seasons (Table 3.5). Generations crosses of Nerica 3 x Basmati 370 and Nerica 2 x Basmati 370 had the highest number of productive tillers while Nerica 1 and Dourado had the least numbers of tillers (Table 3.5). The variation in the tillering across the seasons could be due to favorable conditions characterized by high water retention capacity. Tillering capacity in rice plant is a vital agronomic character for commercial grain production. Ibrahim et al., (1990) reported that effective tillers were the most reliable trait in selecting rice genotypes for higher grain yield. Similar result was also reported by Zahid et al., (2005) who studied 12 genotypes of coarse rice for yield performance in Kala, Pakistan and they reported significant variation in the number of effective tillers per plant. Therefore, tillering in rice plant plays a vital role in determining grain yield since the number of tillers is closely associated to number of panicles per plant. However, excess tillering leads to high tillering mortality, small panicles, poor grain filling, reduced light penetration and reduced photosynthetic activity in some tillers leading to decline in grain yields (Efisue et al., 2014).

Rice genotypes evaluated in this study displayed wide variability for number of filled grains per panicle. Plants with many panicles per plant tend to compensate for few seeds per panicle. This may be assumed to be due to competition within a panicle. Most genotypes had moderate number of grains per panicle (Table 3.5). Generations crosses of Nerica 3 x Basmati 370 and Nerica 2 x Basmati 370 gave highest number of filled grains per panicle (Table 3.5). Babu et al., (2012) reported significant variation for number of filled grains per panicle, number of filled grains contributed positively to grain yield. The filled grains depend on the rain filling rate and grain filling duration of superior and inferior grains. Luzi-Kihupi (1998) studied interrelationship between yield and selected characters in rice and revealed that plants with large panicles tend to have high grain filling. Moisture stress had adverse effect on grain filling percentage. Water deficit could result in major reduction in grain dry matter in rice. Water stress was likely to be the possible cause of shortage of assimilates supply due to inhibition of photosynthetic processes; this was reported by Yoshida (1981).

Genetic variation observed for panicle weight and thousand grain weights among the genotypes studied indicated that the genotypes were genetically diverse and that the variations were due to presence of inherent genetic differences among the genotypes (Table 3.5). A similar result was reported by (Akinwale et al., 2011; Osman et al., 2012). Two rainy seasons composed of varied levels of environmental factor, however genotypes performance across the rainy seasons did not vary considerably. Genotypes maintained high grain yield through compensatory effect of having large number of panicles per plant, number of filled grains per panicle but with lower thousand grain weight. The findings agrees with results reported by Laza et al., (2004) who concluded that cultivars with large panicles produce fewer tillers and hence fewer panicles than the cultivar with small panicles.

Genotypes differed for plant height among the rainy seasons. The area was appropriate and ideal locations for the growing of these genotypes, since the genotypes appeared to be well adapted to this location (Table 3.5). The variation in the plant height for the two seasons could be due to the supplemental irrigation and ambient temperature at Mwea Research Station during the crop growing period that probably stimulated vegetative growth due to accumulation of assimilates in the stem resulting to increase in plant height. The results further revealed that rice plants with relatively short to intermediate height exhibited higher grain yields. This could be due to the favorable growing conditions at Mwea Research Center characterized by good soils with retention capacity and high humidity (Table 3.5).

Hussain et al., (2005) reported that transplanting time, sowing method, water and soil condition affect plant height in rice plants. Rice plants with short to intermediate height generally have higher grains yields. This could be due to attribute to the supply of assimilates to developing grains. Genotypes with tall rice plants such as Dourado recorded low grain yield. This may be due utilization of assimilates in vegetative growth rather than being imported for seed formation and grain fillings.

Yoshida (1981) reported that high grain yield in rice varieties with short plant height was associated with increase in lodging resistance of the rice plant. Therefore, selection of short to intermediate plant type would be advantageous in relation to grain yield (Table 3.5).

Then highest yield was recorded in the generation crosses of Nerica 3 x Basmati 370 and Nerica 2 x Basmati 370, while Dourado and Nerica 1 had the lowest yield (Table 3.5). The variation in grain yield across the seasons could be due to favorable growing conditions characterized by good soils and as well as rainfall distribution and diverse genetic composition of the genotypes. Similar results was observed by Xing and Zhang (2010) who reported that rice varieties exhibit tremendous variation in grain yield due to diversity in genetic constitution. The genotypes, Nerica 3 x Basmati 370, Nerica 2 x Basmati 370 and Basmati 370 consistently maintained higher grain yields across the seasons suggesting a wider adaptability to varying environments (Table 3.5).

Among the characters, highest values of PCV and GCV were recorded for grain yield (22.5), number of unfilled grains (22.9) and number of productive tillers (20.2), and the lowest PCV and GCV were for panicle length (3.0) and plant height (4.8) (Table 3.11). The estimates of PCV were slightly higher than the corresponding GCV estimates for all the traits studied; this indicates that the characters were less influenced by the environment This also imply high coefficients of variability indicates that there is a scope of selection and improvement of this traits, low values indicates the need for creation of variability either by hybridization or mutation follow by selection. Similar results noticed earlier by many researchers Ogunbayo et al.,(2014); Idris et al. (2012). The magnitude of the genotypic variance (heritable) of these characters were higher than the environmental (non-heritable), indicating that the genotypic components was the major contributor to total variance. Sadeghi (2011) reported similar results.

Although GCV revealed the presence of high level of genetic variation, heritability alone provides no indication of the amount of genetic improvement that would result from selection of individual genotypes (Table 3.11).

This study revealed heritability in broad sense for the agronomic traits studied, to vary from 1.7 to 97.6 percent. Among the yield characters, highest heritability values were recorded in days to heading, days to 50% flowering, days to maturity, number of productive tillers, number of filled grains and thousand gain weights (Table 3.11). Similar findings were also reported by Karthikeyan et al., (2010) and Anandrao et al., (2011). High heritability values indicated that the character under this study was less influenced by environment in their expression. Estimate of high heritability act as predictive instrument in expressing reliability of phenotypic value, therefore high heritability helps in effective selection for a particular character.

Since rice is produced and marketed according to grain size and shape, shaping the physical dimensions of the varieties are very significant. Length to width ratio is very important in classification of grain shape. The varieties were categorized into three groups as very long, long and medium based on the length of the milled grains. Takoradi (2008) reported that long grain rice is highly demanded by rice consuming population.

All the genotypes exhibited an L/W ratio between 2.1 and 3.0 except two genotypes, suggesting that they were medium in grain shape (Table 3.9). Nerica 1 x Mwur 4 and Nerica 10 x Mwur 4 exhibited a slender shape with relatively high L/W ratio of 3.0 to 3.1. The results was contrary to Yadav et al., (2016) who studied physio-chemical , cooking, pasting and textual properties of some Indian rice varieties of Basmati and non-Basmati and reported a length to width ratio of more than 3.0 for Basmati grains was significantly higher than non-Basmati grains (Table 3.9).

Compared to all the genotypes, generation crosses of Nerica 3 x Basmati 370 and Nerica 10 x Mwur 4 exhibited the highest grain length. However rice breeders consider grain size and grain shape as the most important rice quality parameters when developing rice varieties for commercial production (Table 3.9). Long and slender rice grains are mostly preferred by many consumers and such grains normally fetch higher prices at international market (Singh et al., 2010). The physical attributes exhibited by Nerica 1 x Mwur 4 and Nerica 10 x Mwur 4 can be exploited in a breeding program designed to improve grain quality of local rice cultivars (Table 3.9).

Aroma is important quality trait that influences the eating qualities and consumer preference of particular rice variety. In this study, none of the genotypes exhibited strong aroma like Basmati

370 (Table 3.9). Basmati 370 was preferred in terms of strong aroma. These results was in agreement with the results of Luzi-Kihupi et al., (2007) who assessed the cooking and eating qualities of mutant lines found from irradiating a local rice cultivar and reported that the test panel rated Supa parent variety as good in terms of aroma and SSD 7 as normal. Environmental factors such as abiotic stress, flowering time, temperature and storage time have been reported in previous having influence on the aroma quality (Itani et al., 2004). The wide range of expression of aroma arising from segregating population between aromatic and a non-aromatic genotype was also reported by Kimani et al., (2013). This may be an indication of promising yield improvement with hybridization breeding; the aromatic may be further incorporated into these improved lines through back crossing method (Table 3.9).

Rice yield was positively and significantly correlated with thousand grain weight (r=0.27), number of filled grains (r=0.80), number of productive tillers (r=0.79), plant height (r=0.32) and days to maturity (r=0.21), but negative significant showed correlation with number of empty grain per panicle (r= -0.55) (Table 3.8). The clear variation in the attributes studied amongst the rice genotypes are important contributors to variation in grain yield. High significant treatment effect for most characters as obtained indicated that the genotypes evaluated differed significantly in these characters. Kumar et al.,(1999) observed variability in number of productive tillers, number of unproductive (empty) tillers, number of filled grains and yield per plot.

Some rice attributes are of paramount importance to achieve maximum potential yield. Thousand grain weight, number of filled grains per plant, yield per plant correlated positively and significant with rice yield. Similar results had been obtained by (Ashura 1998).

Furthermore, rice yield was significantly reduced as a result of days to 50% flowering (heading) (r= -0.06) (Table 3.9). This finding is similar with work of Moncade et al., (2001) who obtained negative correlation of yield on days to 50% heading . The breeder must however pay attention to these attributes that show negative correlation that exists between grain yield and those attributes. Thus, in order to increase yield, it is important to reduce plant height, days to 50% heading, as the longer the plants stay in the field, the less the productivity they are as observed in some studies.

3.6. Conclusion

Out of the 14 rice cultivars evaluated, Nerica10, Nerica1 and of Basmati 370 were early maturing with short to intermediate plant height, while generations crosses of NERICA 3 x Basmati 370, NERICA 2 x Basmati370 and Basmati 370 consistently maintained high yield across the seasons. In addition, generation of crosses of Basmati 370, Nerica 2 x Basmati 370 and Nerica 3 x Basmati 370 had high physical grain quality and aroma compared to other non-Basmati rice varieties. This indicated that Basmati 370 is a promising cultivar for eventual release in Kenya.

CHAPTER FOUR: COMBINING ABILITY FOR YIELD COMPONENTS AND QUALITY TRAITS IN UPLAND RICE CULTIVARS

4.0 Abstract

Breeding rice for yield potential and grain quality requires careful selection of the parental genotypes that possess high yield potential and with good cooking and eating characteristics. Rice in eastern Africa is predominantly grown by smallholder farmers with an estimated yield of about 1,800 kg ha^{-1}. The understanding of genetic variability and mode of gene action for agronomic and yield traits are important in formulation of effective rice breeding program for genetic enhancement of grain yield. The objective of this study was to determine the combining ability and heterosis for agronomic and yield traits in indica and japonica rice crosses.

Twenty one F_1 hybrids were generated from crosses between seven male indica parents (NERICA 3, BASMATI 370, KUCHUM, MWUR 2, NERICA 1, NERICA 10 and NERICA 2) and three japonica females (DOURADO, KOMBOKA and MWUR 4) using North Carolina Design II mating system. The 21 F1 hybrids and their 10 parents were evaluated at Mwea Research Station during the cropping season of 2017. Data was collected on agronomic and yield traits and subjected to analysis of genetic designs in R (AGD-R) version 3.0.

The results showed that general combining ability (GCA) was highly significant ($P \leq 0.01$) for days to maturity, plant height, panicle length, flag leaf, number of productive tillers, number of spikelets, 1000 grains weight and grain yield indicating the dominance of additive gene action in the expression of these traits. Specific combining ability (SCA) was significant ($P \leq 0.05$) for days to maturity, plant height, panicle length, flag leaf length, number of spikelets, number of productive tillers, 1000 grain weight and grain yield suggesting the dominance of non-additive gene action in the control of these traits. Basmati 370, Nerica 2 and Nerica 3 were best general combiners for grain yield. Hybrids Komboka x Basmati 370, Dourado x Nerica 1 and Mwur 4 x Nerica 3 were good specific combiners for grain yield. The best specific combiners originated from high x high GCA combinations and could be attributed to additive x additive type of gene actions thus the yield potential of these crosses can be fixed in subsequent generations and produce desirable transgressive segregants which can be recognized by pedigree breeding method. However, high SCA effects of hybrids from high x low GCA combining parents would be unfixable in subsequent generations and thus requires modification of the breeding method to accommodate both additive and non-additive genetic effects in order to fix the yield potential of these crosses in later generations

4.1. Introduction

Rice is the second most important food crop globally after maize and provides over 20 % of the daily calorie intake for 3.9 billion people globally (Kohnaki et al., 2013).

Annual rice production in Africa was estimated at 31 million t from 11 million hectares under cultivation (FAO, 2017).

Rice forms a larger part of the diet for both urban and rural populations in Kenya. Kenya produces about 140,000 metric tonnes against a demand of over 540,000 metric tonnes per year (MoA, 2014). Unfortunately, rice yield per hectare is low (< 3.6 t ha^{-1}) because smallholder farmers rely on local cultivars with low yield potential, highly susceptible to bacterial leaf blight and rice blast (Kimani, 2010). Small holder farmers at Mwea irrigation scheme mainly grow Basmati rice under irrigated ecosystem. Basmati rice is mainly preferred by most consumers due to its aroma and good cooking qualities (Njiruh et al., 2013). However, Basmati yield per hectare is low (3.0 t ha^{-1}) and upland rice varieties are marginally practiced despite their enormous potential in increasing national production (Kimani, 2010). This stagnation in productivity led to decline in consumption of locally produced rice and increased imports from Pakistan, China, India and Vietnam (MoA, 2014).

Understanding the gene action for yield and yield related traits is a prerequisite for breeding high yielding locally adapted upland rice varieties (Dar et al., 2014). Various biometrical techniques designed to analyze genetic variability for yield related traits have been developed (Comstock and Robinson, 1948; Griffing, 1956; Kempthrone, 1957; Kempthrone and Curnow, 1961). These mating designs provide reliable information about general combining ability (GCA) and specific combining ability (SCA) of the parents and crosses. The differences in GCA are mainly due to additive gene action while the differences in SCA are attributed to non-additive gene effects (Fasahat et al., 2016). Estimation of GCA helps the breeder to identify parents with superior combining ability which may be hybridized to exploit heterosis, and also for development of populations from which agronomical superior lines can be selected (Fasahat et al., 2016).

Previous studies reported an increase in grain yield due to favorable combining ability for characters such as flag leaf area, number of spikelets per plant and number of filled grains per panicle (Vanaja and Babu, 2004).

Objective of this chapter was to determine the combining ability for yield and grain quality traits in upland rice cultivars.

4.2. Materials and Methods:

4.2.1. Study Location:

Details of study location are described in Chapter 3 (3.2.1)

4.2.2. Plant materials:

The experimental materials used in this study were seven *indica* male and three *japonica* female rice cultivars. The characteristics of these genotypes are shown in (Table 3.1). The plant materials were obtained from Kenya Agriculture Research and livestock organization (KARLO) Mwea and chose based on yield potential, resistance to both biotic and abiotic stresses and high grain quality attributes.

4.2.3. Hybridization

At flowering stage of the rice cultivars, emasculation was done between 6 and 9 a.m. before anthesis. The female panicles that had arisen 5 to 10 cm from the leaf sheath were selected for emasculation. Using a sharp small scissors, the upper and lower spikelets were removed leaving the middle part in order to expose the anthers. Then anthers were safely removed using a pair of forceps. Immediately after emasculation, the panicles were covered with a poly bags to protect it from unwanted foreign pollen. Pollination commenced from 10 a.m. to 1 p.m. the time when the maximum anther dehiscence was observed. The polythene bag covering the emasculated panicle was lifted and the male blooming panicle was carefully positioned above the female panicle. The two culms of both parents were covered with a bag and fastened together with an office clip (Coffman and Herrera, 1980).

Table 4.1. North Carolina Mating Design II used to generate rice populations for estimating GCA and SCA.

	Female Parents		
Male Parents	8 (Dourado)	9 (Komboka)	10 (Mwur 4)
1 (Basmati 370)	1x8	1x9	1x10
2 (Kuchum)	2x8	2x9	2x10

3 (Mwur 2)	3x8	3x9	3x10
4 (Nerica1)	4x8	4x9	4x10
5 (Nerica10)	5x8	5x9	5x10
6 (Nerica2)	6x8	6x9	6x10
7 (Nerica3)	7x8	7x9	7x10

4.2.4. Harvesting of F1 seeds

Most of the F_1 seeds lost their green colour at about 27 days after pollination and were considered mature. The seeds from each female were harvested, threshed and bagged separately. The seeds were sun dried and stored in khaki envelops.

4.2.5. Evaluation of F1 Progeny

The 10 parents and their 21 F_1 hybrids were evaluated in Mwea Research Station. The trial was laid out in randomized complete block design with tree replications. Each entry was planted in a single row consisting of 15 plants in each row with a spacing 20 x 20 cm with two seed per hill. Gaping and thinning was carried out when the seedlings was 2-3 weeks to ensure uniform plant density. DAP fertilizer (18:46:0) was applied during planting at a rate of 50 kg N ha $^{-1}$ and 40 P ha $^{-1}$. NPK (17:17:17) fertilizer was applied at a rate of 120 kg N ha $^{-1}$, 30 kg P ha $^{-1}$ and 90 kg K ha -1 for first dressing, and Calcium ammonium nitrates (CAN) was also applied at panicle initiation stage at a rate of 100 kg N ha $^{-1}$. The trial was irrigated twice a week and pesticide (Duduthrin 1.75 EC, Lambda-cyhalothrin 17.5 g/L) was applied every two week at a rate of 50 ml/20L of water to control stem borer, fall armyworm and leaf hoppers. Hand weeding was carried out at the interval of 20, 40 and 60 days after planting.

4.3. Data Collection

Data for agronomic traits were collected according to the procedure outlined in IRRI (2013). The data were collected at appropriate stage of crop development at vegetative, flowering, maturity and harvesting stages as referred to in Chapter three. Sub-section 3.2.1 .

4.4. DATA ANALYSIS

The general analysis of variance to determine the differences between genotypes were performed by genetic designs in R (AGD-R) version 3.0 (Gregorio et al., 2015). The treatment means were compared using least significant differences test (LSD) at $P \leq 0.05$.

4.4.1. Combining Ability Analysis

The variation among the hybrids was partitioned further into sources attributable to general and specific combining ability components in accordance with the procedure suggested by Kempthorne (1957). The mathematical model used to study the general and specific combining ability effects was:

$$Y_{ijk} = m + g_i + g_j + s_{ij} + 1_K + e_{ijk}$$

Where,

Y_{ijk} = value of the hybrid involving i^{th} female and j^{th} male parent in k^{th} replication

m = general mean of all hybrids

g_i = general combining ability effect of i^{th} female parent

g_j = general combining ability effect of j^{th} male parent

s_{ij} = specific combining ability effect of the progeny of $(i \times j)^{th}$ cross.

1_K = effect of k^{th} replication

e_{ijk} = Uncontrolled variation associated with ijk^{th} observation

i = number of female parents (1, 2….f)

j = number of male parents (1, 2 …m)

k = number of replications (1, 2….r)

4.4.2. Estimation of General and Specific combining Ability effects

The relative importance of GCA and SCA were estimated using the general predicted ratio (GPR) for the traits observed (Baker, 1978). The ratio was estimated as follows;

$$\frac{2\sigma^2 GCA}{(2\sigma^2 GCA + \sigma^2 SCA)}\ldots\ldots$$

Where, $2\sigma^2$GCA and σ^2SCA are the variance components for GCA and SCA, respectively estimated from Griffing's method model 1 (fixed effects). Ratios close to one indicate additive effects are important in the inheritance of the trait while ratios close to zero indicate dominance and epistasis effects are important in the inheritance of the trait.

4.5. Results

The results revealed that there were significant differences among the genotypes for all characters studied except 1000 grain weight (Table 4.2).

The analysis of variance show highly significant differences in the genotype studied for days to maturity (155.19***) among the genotypes (Table 4.2). The analysis of variance for combining ability for days to maturity was highly significant among male (128.0***) and significant for male x female (11.1 *) (Table 4.3).

There was highly significant differences for plant height among the genotypes (135.2**) (Table 4.2). Analysis of combining ability was highly significant for plant height among the male (313.0 **) and significant for female parents (87.0 *). The mean squares due to male x female interaction effects were significant (54.4**) (Table 4.3).

The genotypes studied for panicle length, analysis of variance showed significant differences among the genotype (10.78*) (Table 4.2). The analysis for combining ability showed significant differences for panicle length among the male (19.7**) and female (16.3*), while non-significant differences were observed in male x female interaction for panicle length (Table 4.3).

Compared to the genotypes studied, there was difference among the genotypes and analysis of variance showed highly significant for flag leaf length (27.28***) (Table 4.2). Combining ability analysis for flag leaf length was highly significant among the male (58.6***), significant among the females (18.1*) and male x female interaction (13.2*) (Table 4.3).

The analysis of variance studied showed significant difference in the number of spikelet (7.90**) among the genotypes (Table 4.2). Combining ability analysis showed significant difference for the number of spikelet per panicle among the male (15.3**) and female (10.9*) but there was no-significant difference among the interaction of male x female (3.7) (Table 4.3).

The analysis of variance showed highly significant genotype difference for number of productive tillers per panicle (52.12***) among the genotypes studied (Table 4.2). The analysis of combining ability showed highly significant for number of productive tillers among the male (107.7***), while significant for female (52.8**) and male x female interaction (24.2**) (Table 4.3).

The difference in the analysis of variance for number of filled grains was highly significant (61.3***) among the genotypes studied (Table 4.2). Number of filled grains was highly significant among the males (88.3***), and significant among the females (50.0*) and male x female interactions (24.3*) (Table 4.3).

The analysis of variance showed non-significant genotype difference for thousand grain weight (8.08) among the genotypes studied (Table 4.2). The analysis of combining ability showed non-significant for thousand grain weight among the males (9.6), females (9.2) and male x female interactions (7.2) (Table 4.3).

The study showed difference among the genotypes studied and analysis of variance showed highly significant for grain yield (1.88***) (Table 4.2). The analysis of combining ability showed highly significant for grain yield among the males (3.2***), while significant for females (3.5**) and male x female interactions (1.0***) (Table 4.3).

The differences between parents were highly significant for all the characters except for thousand grain weights. The variance due to general combining ability (GCA) was found to be significant and greater than SCA for all the traits except grain yield (Table 4.3). The magnitude of SCA was lower than GCA variance for all characters except grain yield which was further supported by high magnitude of σ^2A / σ^2D ratios (Table 4.3).

Table 4.2. Analysis of Variance (ANOVA) for Agronomic and Yield Traits.

Source of V	Df	**DM**	**PH**	**PL**	**FL**	**NPT**	**NSP**	**NFG**	**TGW**	**GY**
Rep	2	13.44	1.0	14.11	2.11	42.39	2.04	54.33	2.10	0.10
Genotype	20	155.19***	135.2**	10.78*	27.28***	52.12***	7.90**	61.35***	8.08	1.88***
Residual	40	4.8	20.88	4.74	6.21	7.56	2.73	10.7	11.33	0.22

Table 4.3. Analysis of variance for combining Ability of 10 parents and their 21 F_1 hybrids for various yield agronomic characters.

Source	Df	DM	PH	PL	FL	NSP	NPT	NFG	TGW	GY
Rep	2	13.4	1.0	14.1	2.1	2.0	42.4	54.3	2.1	0.1
Male	6	128.0***	313.0**	19.7**	58.6***	15.3**	107.7***	88.3***	9.6	3.2***
Female	2	1.8	87.0*	16.3*	18.1*	10.9*	52.8**	50.0*	9.2	3.5***
Male: Female	12	11.1*	54.4*	5.4	13.2*	3.7	24.2**	24.3*	7.2	1.0***
Error	40	4.9	20.9	4.7	6.2	2.7	7.6	107.7	11.3	0.2
$^{\delta}$m (male)		90.8	28.7	1.6	5.0	1.3	9.3	71.1	0.3	0.2
$^{\delta}$ f (female)		0.0	1.6	0.5	0.2	0.3	1.4	12.2	0.1	0.1
$^{\delta}$ m x f		2.1	11.2	0.2	2.3	0.3	5.6	45.3	0.0	0.2
$^{\delta}$ A		203.5	67.4	4.5	11.8	3.5	23.2	181.4	0.8	0.8
$^{\delta}$ D		8.3	44.7	0.9	9.3	1.3	22.2	181.3	0.0	1.0
$^{\delta}$ A/$^{\delta}$ D		24.6	1.5	5.1	1.3	2.8	1.0	1.0	0	0.8

*Significant at 5 % level, **Significant at 1 % level, ***Significant at ≤ 0.01 level, $^{\delta}$ A: Additive gene, $^{\delta}$ D: Dominance gene, $^{\delta}$ A/$^{\delta}$ D: Ratio of additive to dominance gene, DM: days to maturity, PH: Plant height, PL: Panicle length, FL: Flag leaf length, NSP: Number of spikelet, NPT: Number of productive tillers, NFG: Number of filled grains, TGW: Thousand grain weight, GY: Grain yield

4.5.1. GCA and SCA for Agronomic and Yield Traits

Parents with high mean performance also had positive GCA for positive traits of panicle length, number of spikelet, number of productive tillers, number of filled grain, thousand grain weight and grain yields. On the other hand, parents with low performance estimates and negative GCA are relative good in days to maturity and plant height (Table 4.4).

GCA effects for this trait revealed that Nerica 1 (-5.52) and Nerica 2 (-8.19) showed strong negative effects, while four genotypes showed negative significant GCA effects including Nerica 10 had negative GCA effect (-9.97), followed by Nerica 3 (-5.97) and Mwur 2 (-0.32) respectively (Table 4.4).

Only two parents possessed significant GCA effect at level 5% including Basmati 370 (12.2) and Nerica 2 (1.14). However, only six parents (4 males and two females) possessed significant negative GCA effect for plant height. Among genotype Mwur 2 (-5.75) showed high negative GCA effect followed by Nerica 1 (-.3.63), Nerica 3 (-2.97), Komboka (-1.62), Nerica 10 (-1.41) and Dourado (-0.67) (Table 4.4).

The estimates of GCA effect revealed that, Nerica 2 (1.73) and Nerica 3 (0.51) showed significant GCA effect for flag leaf, the rest of the cultivars were non-significant (Table 4.4).

All the genotypes showed non-significant GCA effect for flag leaf except Nerica 2 (1.54), Nerica 3 (1.10) and Nerica 1(1.4) (Table 4.4).

From all the parents, Nerica 1 and Nerica 2 revealed highest positive GCA effects for number of spikelets 1.10 and 0.02 respectively (Table 4.4).

With regards to number of productive tillers, all lines were non-significant except Nerica 3 (6.8) and Komboka (0.40) showed positive GCA effects, while Nerica 1 revealed negative (-0.29) GCA effect (Table 4.4).

From all the cultivars studied for filled grains per panicle, none of the cultivars were significant (Table 4.4).

The parents Nerica1 and Komboka had positive significant GCA effects on thousand grain weight (Table 4.4).

Positive high GCA effects was showed in parents Basmati 370 (0.88), Nerica 3 (0.42) and Nerica 2 (0.36), thus Nerica 1 had negative GCA effects in spite of showing positive GCA effects in thousand grain weight (Table 4.4).

Table 4.4: General combining ability effects of 10 cultivars for different yield characters

Genotypes	**DM**	**PH**	**PL**	**FL**	**NSP**	**NPT**	**NFG**	**TGW**	**GY**
Male									
Basmati 370	12.14	**12.2****	2.06	1.54	-1.65	-0.62	0.52	0.66	0.88**
Kuchum	11.81	0.37	-0.27	0.10	0.46	-2.62	1.30	0.04	-0.13
Mwur 2	5.70	-5.75	-1.38	-5.57	2.02	-3.40	2.63	-0.09	-0.90
Nerica 1	-5.52**	-3.63	-1.60	**1.4****	1.10**	-0.29*	-14.92	**2.2***	-0.35**
Nerica 10	-9.97	-1.41	-1.05	-0.13	-0.87	1.83	-9.37	0.48	-0.30
Nerica 2	-8.19**	1.14**	1.73**	1.54**	0.02**	-1.73	3.86	0.71	0.36**
Nerica 3	-5.97	-2.97	0.51	1.10**	1.13	**6.8***	15.97	0.44	0.42**
Female									
Dourado	0.06	-0.67	-0.51	-0.41	-0.57	-1.75	-0.05	-0.73	0.09
Komboka	0.25	-1.62	-0.51	-0.65	-0.24	0.40*	-4.86	0.18*	-0.45
Mwur 4	-0.32	2.29	1.02	1.06	0.81	1.35	4.90	0.55	0.36

Estimate of SCA effect varied among the crosses (Table 4.5). Only two cross combination of Dourado x Mwur 2 (2.8) and Komboka x Nerica 2 (1.52) showed desirable direct positive SCA effect for this character, however some genotypes revealed negative direct SCA effect for this trait, and the cross combination were Komboka x Nerica 1 (-0.14) and Komboka x Nerica 3 (-0.37) (Table 4.5).

Estimates of SCA effect ranged from -5.22 to 10.17. Crosses of Komboka x Basmati 370, Mwur 4 x Nerica 3 (10.15) and Dourado x Nerica 1 (2.44) had positive SCA effects, while Mwur 4 x Basmati 370 (-0.06) showed significant negative desirable SCA effect for plant height (Table 4.5). As regards to SCA effects of hybrids, two hybrids exhibited positive significance which were Dourado x Nerica 3 (2.27) and Mwur 4 x Nerica 3 (1.54), while Dourado x Kuchum (-1.83) showed negative SCA effects respectively (Table 4.5).

Among the genotypes studied, Dourado x Nerica 1 (2.19), Komboka x Nerica 10 (2.32) and Dourado x Nerica 3 (0.86) recorded high positive SCA effects for flag leaf length (Table 4.5).
Three crosses exhibit significant positive SCA effects for number of spikelet and only one with significant negative SCA effects, these genotypes with positive effects were Dourado x Nerica 3 (2.45), Komboka x Nerica 10 (0.35) and Komboka x Nerica 2 (0.13), while Komboka x Nerica 3 (1.65) displayed negative effects (Table 4.5).
With regards to specific combining ability effects of crosses, two hybrids depicted positive significant specific combining ability effects, these crosses were Komboka x Kuchum (4.38) and Komboka x Nerica 2 (2.49), while Dourado x Kuchum (-4.47) had negative SCA effects on number of productive tillers per plant (Table 4.5).

Two crosses exhibited significant and positive desirable specific combining ability effects, those crosses were Dourado x Nerica 10 (12.93) and Dourado x Mwur 2 (12.60), while Dourado x Nerica 2 (-13.61) exhibited negative specific combining ability (Table 4.5).

Hybrid cross Komboka x Nerica 1 (2.17) and Komboka x Basmati 370 (0.15) were observed with significant positive SCA effects, while cross Dourado x Nerica 1 (-3.52) displayed significant negative SCA effects on thousand grain weight (Table 4.5).

Significant desirable SCA effects were recorded for crosses Mwur 4 x Nerica 3 (0.71), Dourado x Nerica 1 (0.25) and Komboka x Basmati 370 (0.21), meanwhile hybrid Mwur 4 x Nerica 10 (-0.83) recorded significant negative SCA effects (Table 4.5).

Table 4.5. Specific Combining Ability of 21 F_1 hybrids for diverse agronomic characters

Cross Combination	**DM**	**PH**	**PL**	**FL**	**NSP**	**NPT**	**NFG**	**TGW**	**GY**
Dourado x Basmati 370	-1.29	-1.44	1.51	-0.92	-0.54	1.52	-6.29	-0.17	-0.21
Komboka x Basmati 370	0.86	**1.51***	-0.83	0.32	-0.21	-1.29	-1.14	**0.15****	**0.21****
Mwur 4 x Basmati 370	0.43	**-0.06***	-0.68	0.60	0.75	-0.24	7.43	0.01	0.00
Dourado x Kuchum	-0.29	-1.56	**-1.83***	-1.48	0.02	**-4.47***	1.60	0.38	0.15
Komboka x Kuchum	1.19	1.73	1.17	-0.24	0.68	**4.38***	2.08	-1.13	-0.10
Mwur 4 x Kuchum	-0.90	-0.17	0.65	1.71	-0.70	0.10	-3.68	0.74	-0.05
Dourado x Mwur 2	**2.8***	3.56	0.95	1.52	-0.54	0.97	**12.60***	0.93	0.64
Komboka x Mwur 2	-1.03	0.17	-0.71	-0.90	1.13	-2.84	-5.92	-0.06	-0.09
Mwur 4 x Mwur 2	-1.79	-3.73	-0.24	-0.62	-0.59	1.87	-6.68	-0.88	-0.54
Dourado x Nerica 1	-0.95	**2.44****	0.84	**2.19****	0.24	1.86	-3.51	**-3.52****	**0.24****
Komboka x Nerica 1	**-0.14****	-0.94	-0.83	-1.24	-0.43	-1.62	1.30	**2.17****	-0.22
Mwur 4 x Nerica 1	1.10	-1.51	-0.02	-0.95	0.19	-0.24	2.21	1.35	-0.01
Dourado x Nerica 10	-1.17	1.56	0.95	0.41	-0.65	3.08	**12.93***	1.40	0.43
Komboka x Nerica 10	-2.03	1.17	-0.05	**2.32****	**0.35****	-0.06	-1.92	-0.04	0.41
Mwur 4 x Nerica 10	3.2*	-2.73	-0.90	-2.73	0.30	-3.02	-11.02	-1.36	**-0.83***
Dourado x Nerica 2	-0.95	0.67	-0.16	-2.59	-0.87	-2.03	**-13.61***	0.01	-0.56
Komboka x Nerica 2	**1.52****	1.29	0.51	2.32	0.13**	**2.49****	5.19	-0.62	-0.17
Mwur 4 x Nerica 2	-0.57	-1.95	-0.35	0.27	0.75	-0.46	8.43	0.61	0.73
Dourado x Nerica 3	1.83	-5.22	**2.27***	**0.86****	**2.41****	-0.92	-3.73	0.97	-0.69
Komboka x Nerica 3	**-0.37****	-4.94	0.73	-2.57	**-1.65***	-1.06	0.41	-0.49	-0.03
Mwur 4 x Nerica 3	-1.46	**10.16****	**1.54****	1.71	-0.70	1.98	3.32	-0.48	**0.71****

*Significant at $P \leq 0.05$, ** Significant at $P \leq 0.01$ and *** Significant at $P \leq 0.001$ DM: Days to Maturity, PH: Plant height (cm), PL: Panicle length (cm), FL: Flag leaf length (cm), NSP: Number of spikelet per panicle, NPT: Number of productive tillers, NFG: Number of filled grains, TGW: Thousand grain weight (g) and GY: Grain yield (t/ha^{-1})

4.6. Discussion

Analysis of variance for various genotypes showed significant differences for all traits studied except thousand grain weights (Table 4.2). There are two types of gene action, additive and non-additive gene action. A high GCA effect for a particular trait indicates the additive gene effect for the trait governed by the genes in parents concerned. Further Analysis of GCA/SCA variances showed (Table 4.3) that the nature of gene action was additive due to high magnitude of fixable genetic component for days to maturity, plant height, panicle length, flag leaf, number of spikelet per panicle, number of filled grains per panicle and number of productive tillers per panicle. Non-additive gene action was dominant for thousand grain weight and grain yield. These results are contrary to the findings of Sathya and Jebaraj (2015) who reported dominance of non-additive gene action for all the agronomic traits studied under aerobic condition. Previous studies have reported predominant role of additive gene action in the control of yield traits (Chakraborty et al., 2009; and Vivekanandan, 2013). Furthermore, key role of non-additive gene effects in the inheritance of agronomic and yield traits were also reported (Muhammed et al., 2010 and Hasan et al., 2015)

The parental genotypes such as Basmati 370 and Nerica 2 exhibited high and positive GCA effects for plant height (Table 4.4), Nerica 2 consistently showed high and positive GCA effects for plant height, panicle length, flag leaf, number of spikelet per panicle and grain yield (Table 4.4) suggesting their desirability for improvement of positive agronomic and yield traits because they contributed to higher grain yield, in contrast to parents with low and negative GCA estimates. The result was in association with Swamy et al., (2003).

The parents such as Basmati 370, Nerica 2 and Nerica 3 had high and positive GCA effects for grain yield indicating that these parents were good general combiners for grain yield (Table 4.4). Previous studies also reported good general combiners for agronomics and yield traits in rice genotypes (Raju et al., 2014). Nerica 1 and Nerica 2 are preferred for improvement of negative traits of grain yield such as days to maturity and plant height. Previous studies reported the significance of using parents with high and positive GCA effects for the improvement of positive agronomic traits (Mirarab et al., 2011 and Malembe et al., 2017)

This study showed that higher GCA variances for days to maturity, plant height, panicle length, and flag leaf, number of fertile spikelet per panicle and grain yield (Table 4.4). Mirarab et al., (2011) conducted study on combining ability and genetic parameters of yield and yield components in rice. Mirarab et al., (2011) reported that GCA was only significant for total number of kernels per panicle, number of filled grains and grain yield per plant implying that additive gene action was predominant in the control of these traits. Previous research also reported the preponderance of additive gene action in the inheritance of days to maturity, number of productive tillers, number of panicles per plant and 1000 grain weight (Dar et al., 2014). Therefore, it is suggested that a breeding method that would take care of the fixable gene effects for exploiting the dominance effects may be more efficient for the improvement of grain yield (Chakraborty et al., 2009).

The generations crosses of, Mwur 4 x Nerica 3, Dourado x Nerica 1 and Komboka x Basmati 370 were good specific combiners for grain yield (Table 4.5). All the high yielding originated from high x high GCA combinations attributable to additive x additive type of generations thus the yield potential of these hybrids can be fixed in subsequent generations (Sandhykishore et al., 2011). Negative SCA effects for grain yield recorded in hybrids (Mwur 4 x Nerica 10) suggesting low yield potential (Table 4.5). This implies that Mwur 4 x Nerica 10 originated from high x low GCA combinations while the rest of the crosses with low and negative SCA effects originated from low x high GCA combination (Table 4.5). The high yield potential observed in the hybrids could be attributed to interaction between positive alleles in the good combiner and negative alleles in the poor combiner (Chakraborty et al., 2009). In the future later generations, these hybrids would produce desirable transgressive segregants upon modification of the conventional breeding methodology to accommodate both additive and non-additive genetic effects. This study showed that the parents with high GCA estimates were not always the best general combiners (Table 4.4). The results also indicated that parents with high GCA effects (Basmati 370, Nerica 2 and Nerica 3) were the best general combiners for specific trait, but none of the parents or the specific crosses was best for all the characters studied (Table 4.5). Previous studies reported the similar results (Chakraborty et al., 2009 and Malemba et al., 2017).

4.7. Conclusion

In this study, Basmati 370, Nerica 2 and Nerica 3 with their hybrids (Mwur 4 x Nerica 3, Komboka x Basmati 370 have considerable potential that can be exploited to develop rice varieties with high yield potential. The non-significant effect displayed by some crosses for various yield traits could be due to the presence of unfavorable genetic combinations of the parents for agronomic and yield characters.

CHAPTER FIVE: GENERAL DISCUSSION, CONCLUSIONS AND RECOMMENDATIONS

5.0. GENRAL DISCUSSION AND CONCLUSION

The best parent was Basmati 370, with high grain yield per plant, long grain category with strong aroma. The next best parent identified was Nerica 3 and Nerica 2 with high grain yield and significant GCA effects (Table 3.9).

The PCV was slightly higher the GCV for all the traits studied which indicated that the traits were highly influenced by environment, though the variations between them were of lower extent. High estimates of GCV and PVC were found for grain yield, number of productive tillers and number of filled grains per panicle suggesting the phenotypic expression of the traits was more influenced by genetic factors than the environment (Table 3.11). The high heritability (Table 3.11) coupled with high genetic advance recorded for some of the traits indicate the prevalence of additive gene effects which were affected by environment hence the possibility of their environment through selection. Genetic coefficient of variation (Table 3.11) contributed to a greater proportion of variation that existed amongst the rice genotypes. Therefore, a breeder would need to pay attention to the negative correlations that exist amongst the characters as these may influence other important agronomic traits such as grain yield as shown in (Table 3.8).

This study revealed that the GCA and SCA effects were significant for grain yield and all the other traits except thousand grain weights, suggesting the importance of both additive and non-additive gene action in conditioning these traits as shown in (Table 4.3). Analysis of GCA/SCA predictability ratio showed that non-additive gene action was more important than additive gene action for grain yield, spikelet fertility, number and weight of grains per panicle (Table 4.3). The GCA and SCA effects as per the performance of parents and hybrids disclosed that none of the parents or crosses was a good general combiner for the entire traits studied (Tables 4.4 and 4.5). The parental lines used in the generation of crossing here, could be useful in rice breeding programs in Kenya in the future.

5.1. RECOMMENDATIONS

1) The parents which were used in development of this hybrid can be utilized in development of super hybrids in future studies.

2) The experimental promising hybrids developed may be further tested extensively in different agro-climatic zones over seasons for their superiority and stability before commercial release.

3) Effective genetic improvement in grain yield would be easier through indirect selection for components traits such as days to maturity, panicle length, and number of productive tillers per panicle, number of filled grains per panicle and thousand grain weight which indicated high positive phenotypic correlation coefficients with the grain yield.

REFERENCES

Acguaah G. (2012). Principles of plant genetics and breeding (2nd ed.). Oxford, UK: Wiley-Blackwell.

Adu-Kwarteng, E. Ellis, B. W. O. Oduro, B. I. and Manful, J. T. (2003). Rice grain quality: a comparison of local varieties with new varieties in Ghana. Food control 14: 507 – 514 p.

Africa Rice Center (WARDA). (2008). NERICA: The New Rice for Africa Compendium (E.A. Somado, R.G Guei, and S.O Keya, eds.) (2008 edition). Cotonou-Benin: Africa Rice Centre. www.warda.org

Akinwale, M. G., Gregorio, G., Nwilene F., Akinyele, B. Ogunbayo, S. A., and Odiyi, A.C. (2011). Heritability and correlation coefficient analysis for yield and its components in rice (*Oryza Sativa* L.). African journal of Plant Science, 5(3):207- 212 p.

Akinwale, M. G., Ogunbayo, S. A.,Sanni, K. A. and Shittu, A. (2014). Genetic variation and heritability of yield and related traits in promising rice genotypes (Oryza sativa L). Journal of plant breeding and crop science. 6(11),153-159 p.

Ashfag, M., Khan, A. S., Khan, S. H. U and Ahmad, R. (2012). Association of various Morphological traits with yield and genetic divergence in rice (Oryza Sativa L) International Journey of Agriculture and Biology 41(4): 1775 – 1779 p.

Babu, V. R., Shreya, K., Dangi, K. S., Usharani, G. and Nagesh, G. P. (2012). Genetic variability studies for qualitative and quantitative traits in popular Rice (*Oryza sativa* L.). Hybrids of India. International Journal of Scientific and Research 2 (6): 2250 – 3153.

Bharali, B. and Barmudoi, B . (2016). Effects of low light intensity on morpho-physiological parameters in rice (Oryza sativa). International Journal of Environmental and Agriculture Research. ISSN 2454-1850.

Burton, G. W. (1952). Quantitative inheritance in grasses. Proc. 6thinta. Grassland cong,1 (2), 227-285 p.

Bouman, B. A. M., Lampayan, R. M, Tuong, T.P. (2007). Water management in irrigated rice: coping with water scarcity. International Rice Research Institute 2007. Los Banos, Philippines. ISBN 978-971-22-0219-3

Chang, T.T. (1976). ‘The origin, evolution, cultivation, dissemination and diversification of Asian and African rice. Euphytica 25: 435-444.

Chakraborty, R., Chakraborty, S., Dutta, B. K., and Paul. S. B. (2009). Combining ability analysis for yield and yield components in bold grained rice (*Oryza sativa* L.) of Assam. Journal of Agronomic. 58 (1), 9-13 p. ISSN 0120-2812.

Chaudhurry, K. and Manoj. (1999). Rate –dependent fracture at adhesive interface. The Journal of Physical chemistry.B, 101(31), 6562-6566 p.

Cheng, Y., Liu, Z., Xu, J., Zhou, T., Wang, M., Chen, Y., Li, H., and Fan, Z. (2008). "HC-Pro protein of sugar cane mosaic virus interacts specifically with maize ferredoxin-5 in vitro and in planta," Journal of General Virology., vol. 89, 2046–2054 p.

Cruz, N. D and Kush, G.S. (2000). Rice grain quality evaluation procedures. Pp15-28. In:

Sing, R.K., and Khush, G.S. (200). Aromatic rice. Oxford and IBH Publishing, Pvt. Ltd. New Delhi, India.

Dar, S. H., Rather, A. G., Ahanger, M. A., and Talib, S. (2014). Gene action and combining ability studies for yield and component traits in Rice (Oryza sativa L.): A Review. Journal of Plant and Pest Science, 1(3), 110-127 p.

Dela Cruz, N., G. S. Khus. (2000). Rice grain quality evaluation procedures: Aromatic rice.(R.K. Singh, U.S, Eds.).

Dingkuhn, M. (1998). Growth and yield potential of Oryza sativa and O. glaberrima upland rice Cultivars and their interspecific progenies. Field Crops Research 1998; 57: 57-69.

Dogara, A. M., and Jumare, A. I. (2014). Origin, Distribution and Heading date in Cultivated Rice. International journal of plant Biology and Research 2 (1): 1- 6 p.

Efferson, J. N. (1985). Rice quality in world markets. In: Rice Grain Quality and Marketing. (G. S. Khush and L. R. Bostian, Eds). International Rice Research Institute. P.O. BOX 933 Manila Philippines.

Efisue, A. A., Umunna, B. C., and Orluchukwu, J. A. (2014). Effect of yield components on yield potential of some lowland rice (*Oryza sativa* L.) in coastal region of Southern Nigeria. Journal of Plant Breeding and Crop Science 6(9): 119-127 p.

Fahasat, P., Abazar, R., Javad, M. R., and John, D. (2016). Principles and Utilization of combining ability in Plant Breeding . Biometrics and Biostatistics International Journal 4(1): 1-24 p.

Food and Agricultural Organization (FAO). (2017). Rice market monitor. Pp 1-42. Bangkok, Thailand. http://www.fao.org/economic/RMM

FAOSTAT. (2014). Statistical Database of the Food and Agriculture Organization.

Futakuchi, K**.,** Manful, J**.,** and Sakurai, T. **(**2013**)**. Improving grain quality of locally produced rice in Africa. Africa rice center (Africa rice)**, C**otonou, Benin**.**

Garris, A.J[1], Tai, T.H, Coburn, J, Kresovich, S, and McCouch, S. (2005). Genetic structure and diversity in Oryza sativa L. Plant Breeding Department, Cornell University, Ithaca, New York 14853-1901, USA. DOI:10.1534/genetics.104.035642

Gregório, B. S., Jorge, A. S and, Rapini, A. (2015). Three new species of Begonia (Begoniaceae) from Bahia, Brazil. PhytoKeys 44: 1–13 p.

Griffing, B. (1956a). Concept of general and specific combining ability in relation to diallel crossing systems. Australian journal of biological sciences, 9(4), 463-493 p.

Griffing, B. (1956b). A general treatment of the use of diallel cross in quantitative inheritance. Heridity, 10 : 31-50 p.

Guo, L., Zhang Z. H. and Zhuang, J. Y. (2013). Quantitative trait Loci for heading date and their relationship with genetic control of yield traits in rice (Oryza sativa).Rice Science 20: 1 -12 p.

Hallerman, E. M. Beckmann, J. S. and Soller, M. (1987). "Statistical power of the North carolina experiment III design in determining the likelihood of success of pedigree breeding programs in selfing plants," Heredity (Edinb). 59,431–440 p.

Hallauer, A. R. Carena, M. J. and Miranda Filho, J. D. (2010). Testers and combining ability in quantitative genetics in maize breeding (383-423 p). Springer New York.

Hammermeister, A. (2008). The Anatomy of Cereal Seed: Optimizing Grain Quality involves getting the right proportion within the seed. Journal of Food Quality. 20,279-289 p.

Hasan, M. M., Rafii, M. Y., Ismail, M. R., Mahmood, M., Rahim, H. A., Alam, M. A. (2015). Marker assisted backcrossing: A useful method for rice improvement. Biotechnol. Equip. 29:237-254 p.

Hossain, M.M, Jahangir, R., , S. M. Raquibul Hasan,R.S.M , Akter,R. , Ahmed, T. and Faruque, A. (2009) .Antioxidant, analgesic and cytotoxic activity of Michelia champaca Linn. Leaf. Stamford Journal of Pharmaceutical Sciences. S. J. Pharm. Sci. 2(2): 1-7 p.

Hussain, S. Ramzan, M. Aslam, M. Manzoor, Z. and Ehsan Safdar, M. (2005). Effect of various stand establishment method on yield and yield components of rice. International Seminar on Rice Crop.212-220 p. Kala Shah Kau, Pakistan.

Ibrahim, S. M., Ramilingan, A. and Subramanian, M. (1990). Path analysis of rice grain yield under rainfed lowland conditions. IRRN. 15(1): 11 p.

International Rice Research Institute (IRRI) (2013). Standard Evaluation System (SES) for Rice (5thd). Manila, Philipine.

Itani, T. Tamaki, M. Hayata, Y. Fushimi, T.and Hashizume, K. (2004). Variation of 2-acetyl-1-pyrroline concentration in aromatic rice grains collected in the same region in Japan and factors affecting its concentration. Plant production science, 7(2), 178-183 p.

Irshad, A. (2001). Factors Affecting Rice Grain Quality; Available at http//www.dawn.com /2001/12/03/ebr10.htm. Accessed 15/12/09.

Jeandroz, S., and Lamotte, O. (2017). Editorial: Plant Responses to Biotic and Abiotic Stresses: Lessons from Cell Signaling. Frontiers in Plant Science 8:1772.

Juliano, B.O. (1985). Criteria and test for rice grain quality. In rice Chemistry and Technology. 2nd Edition, America Association of Cereal, 443-524.

Juliano, B. O., Onate, L.U. and Del Mundo, A. M. (1965). Relation of starch composition, Protein content and gelatinization temperature to cooking and eating qualities of milled Rice. Journal of food technology. 19 (6), 116–12 p.

Kearsey, M. J. P. and Harpal, S. (1996). The genetical analysis of quantitative traits. 1st ed. Chapman and Hall, London, UK. (No. QH457. 7 K24).

Kempthrone, D., and Curnow, R. N. (1961). The partial diallel cross. Biometrics 17(2):229-240 p.

Kempthorne, O. (1957). An introduction to genetic statistics. John Wiley and Sons., Inc., New York.

Kenya Agricultural Research Institute (KARI). (2000). Soil fertility management handbook for extension staff and farmers in Kenya: KARI Technical Note Series. 45 p.

Kimani, J. M. (2010). Genetic studies of quantitative and quality traits in rice under low and high soil nitrogen and phosphorous conditions, and a survey of farmer preferences for varieties. PhD thesis, University of KwaZulu-Natal, Republic of South Africa.

Kimani, J.M, Githiri, S.M., Derera, J., Nyende A.B., and Jedidah. W.D. (2013).Association of Phenotypic trait and variations in SSR Markers for rice grain fragment and Metric Traits Under different Soil Fertility Regimes: East Africa Agriculture Journals: 79(2), 63-71 p.

Kimani, J.M., Tongoona, P., Derera, J., and Nyende A.B. (2011).Upland varieties development through participatory plant breeding. ARPN Journal of Agriculture and Biological Science.6 (9):39-49 p.

Krishnaveni, B. Shobharani, N. and Ramprasad, A. S. (2006).Genetic parameters for quality Characteristics in aromatic Oryza rice 43(3): 234-237 p.

Khush, G. S. (1997). Origin, dispersal, cultivation and variation of rice. Plant Molecular Biology 35: 25-34 p.

Kusterer, B. Muminovic, J. Utz, F. H. Piepho, H. P. Barth, S. Heckenberger, M. Meyer, R. C. Altmann, T. and Melchinger, A. E. (2007). “Analysis of a triple testcross design with recombinant inbred lines reveals a significant role of epistasis in heterosis for biomass-related traits in Arabidopsis,” Genetics, vol. 175, no. April, 2009–2017 p.

Laza, M.R.C. Rebecca, M. Akita, S. Peng, S. (2004). Effect of Panicle Size on Grain Yield of IRRI-Released Indica Rice Cultivars in the Wet Season. Journal of Plant Production Science 7(3):271-276 p.

Li, J. (2003). The Natural History of Rice: Rice. In: Food and culture Encyclopedia: The Gale Group. Inc

Linares, O. F . (2002). African Rice (Oryza glaberrima): History and Future Potential. Proceeding of the National Academy of America; National Academy of sciences; 99 (25):16360-16465 p.

Luzi-Kihupi, A., Mlozi, M. R. S., and Nchimbi-Msolla, S. (2007). Cooking and eating quality of rice yellow mottle virus resistant rice mutants: its implication for future breeding work. Tanzania Journal of Agricultural Science 8(2): 193-202 p.

Luzikihupi, A. (1998). Interrelationship between yield and some selected agronomic characters in rice. Afr. Crop Sci. J. 6(3):323-328 p.

Macauley, H. and Ramadjita, T. (2015). Cereal crops: An action plan for African Agricultural transformation. Dakar, Senegal.

Malembe, G. M. Nzuve, F. M. Kimani, J. M. Olubayo, M. F. and Muthomi, J. W.(2017). Combining ability for drought tolerance in upland rice varieties at reproductive stage. Journal of Agriculture Science 9(3): 138-150 p.

McCouch, S. (2005).The complex history of the domestication of Rice. Annals of Botany 100: 951 – 957 p.

Ministry of Agriculture (2009) and National Rice Development Strategy 2008-2018.Information and Documentation Services. KARI, Nairobi.

Ministry of Agriculture (2010). Economic Review of Agriculture 2010: Central Planning and project monitoring Unit. Nairobi.

Mirarab, M.; Asadollah, A and Mohamad H.P. (2011). Study on combining ability heterosis and genetic parameter of yield traits in rice. African J. Biotech., 10(59): 12512-12519 p.

Momo, J.A. (2013). Effect of withholding irrigation water after complete heading on rice yield and seed quality in Mwea, Kirinyaga county- Kenya. MSc. In Agronomy, Kenyatta University.

Muhammed, Y. S. Javed, I. M. and Muhammad, A. H. (2010). Combining ability analysis of some morpho-physiological traits in Basmati rice. Pakistan Journal of Botany 42(5): 3113-3123 p.

Nduwumuremyi, A. (2013). Mating designs: Helpful tools for quantitative plant breeding analysis. Journal of Plant Breeding and Genetics 1(3): 117-129 p.

Nguyen, N. V. (2001). Rice production , consumption and nutrition. FAO, Rome.

Nguyen, N.V. (2006). Global climate changes and rice food security. International rice commission, FAO, Italy, Rome.

Niu, X. Tang, W. Huang, W. Ren, G. Wang, Q. Gluo, D. and Gao, F. (2008). RNAi-directed down regulation of OsBADH2 results in aroma (2-acetyl-1-pyrroline) production in rice (Oryza sativa L.). BMC plant biology, 8(1), 1.

Norman, J. C. and Kebe, B. (2004). African smallholder farmers: Rice production and sustainable livelihoods. (Pp. 33-64). G. Keerthisingghe (Ed.). Accra, Ghana.

Normille,D. (2004). Yangtze seen as earliest rice site. Science 275:309

Oka, H. I. and Morishima, H. (1967). Variations in the Breeding Systems of a Wild Rice, Oryza perennis. Article in Evolution 21(2):249.

Oko, A. O. Ubi, B. E. and Dambaba, N. (2012). Rice cooking quality and physio-chemical characteristics: A comparative analysis of selected local and newly introduced rice varieties in Ebonyi state, Nigeria. Food and Public Health 2(1):43-49 p.

Okra, H.I. (1988). Origin of Cultivated Rice. Japan Scientific Societies Press, Tokyo.

Onyango, A. O. (2014). Exploring options for improving rice production to reduce hunger and poverty in Kenya. World Environment, 4(4), 172-179 p.

Organization for Economic Cooperation and Development (OECD). (1999). Consensus document on the biology of rice (Oryza sativa) ENV/JM/MONO (vol.99). Paris, France.

Osman, K. A. Mustafa, A. M. Ali, F. Yonglain, Z. and Fazhan, Q. (2012). Genetic variability for yield and related attributes of upland rice genotypes in semi-arid zone (Sudan). African Journal of Agricultural Research 7(33): 4613 – 4619 p.

Ovung, C. Y. Lal, G. M. and Prashant, K. R. (2012). Studies on genetic diversity in Rice (Oryza sativa L). Journal of Agricultural Technology 8(3): 1059 – 1065 p.

Panse, V. G. (1957). Genetics of quantitative characters in relation to plant breeding. Indian Journal of Genetics 17:318 – 328 p.

Pearson, G, W., and Stuiver, M. (1986). High precision calibration of the radiocarbon time scale, 500-2500 BC.Radiocarbon, 28 (2B), 839-862 p.

Porteres, R.(1956). Taxonomie agrobotanique des Riz cultives, Oryza sativa L. et O. glaberrima. Steudel. Journal of Agriculture tropical, Bot. Appl. 3:341-856 p.

Raju, C. D. Kumar, S. S. Raju, C. S. and Srijan, A. (2014). Combining ability studies in the selected parents and hybrids in rice. International Journal of Pure and Applied Bioscience 2(4): 271-279 p.

Ramiah, K. (1937). Rice in Madras - Popular Handbook. Government Press, Madras.

Rickman, J. F. Bell, M. and Shires, D (2006). Seed Quality. Available at http// www.knowledgebank.irri.org. Accessed 21/12/09.

Rohilla, R. Singh. V.P. Singh, U.S. Singh, R.K. and Khush, G.S. (2000). Crop husbandry and environmental factors affecting aroma and other quality traits.201-216 p. In: Sing, R.K., Sing,

Sabesan, T. Suresh, R. and Saravanan, K. (2009). Genetic variability and correlation for yield and grain quality characters of rice grown in coastal saline lowland of Tamiluadu.

Electronically Journal of plant breeding 1: 56 – 59 p.

Sabouri, H. and Nahvi, M. (2009). Identification of major and minor genes associated with heading date in an indica x indica cross of rice (Oryza sativa. L). International Journal of Plant Production. 3(1): 1735-6814 p.

Sadeghi, S. M., (2011). Heritability, Phenotypic correlation and path coefficient studies for some agronomic characters in landraces rice varieties. World Applied Sci. J., 13: 1229-1233 p.

Sathya, R., and Jebaraj, S. (2015). Combining ability analysis of three line hybrids in rice (Oryza sativa L.) under aerobic condition. International Journal of Plant Sciences 10(2):122-129 p.

Schlegel, R.H.J. (2010). Dictionary of plant breeding. 2nd edition, CRC Press, Taylor Francis Group, Boca Raton. Biologia Plantarum, *54*(2), 278-278 p.

Second, G. (1982). Origin of the genic diversity of cultivated rice (Oryza spp.): study of the polymorphism scored at 40 isozyme loci. Japan Journal genet.; 57: 25-57 p.

Selvaraj, I. C., Nagarajan, P., Thiyagarajan, K., Barath, M. and Rabindran, R. (2011).Genetic parameters of variability, correlation and path coefficient studies for Grain yield and other yield attributes among Rice blast disease resistant genotypes of Rice . (Oryza Sativa L). African Journal of Biotechnology 10(17): 3322 – 333 p.

Singh and G.S. Khush (Eds.). Oxford and IBH Publishing, New Delhi, pp: 107-133.

Singh, S. K. Singh, C. M. and La, G. M. (2011). Assessment of genetic variability for yield and its component characters in rice (*Oryza sativa* L). Research in plant Biology 1(4):73-76 p.

Singh, S. P. Singhara, G. S. Parray, G. A. and Bhat, G. N. (2006). Genetic variability and character association studies in rice (Oryza sativa L.). Agricultural Science Digest, 26(3), 212-214 p.

Slaton, N., Moldenhauer, K., Gibbons, J., Blocker, M., Wilson Jr., C., Dilday, R., Robinson, J. and B. Koen. (2000). Grain Characteristics of Rice Varieties. In: Cooperative Extension Service Rice Information,1-8 p.

Sohrabi, M. Rafii, M.Y, Hanafi, M.M. Siti Nor Akmar A, Latif ,M.A. (2012). Genetic diversity of upland rice germplasm in Malaysia based on quantitative traits. Scientific world Journal. 2012; 2012: 416291 p.

Solheim, W.G. II (1972). “An earlier agricultural revolution’. Scientific . Am. 226 (4): 34-41 p.Steel, R.G.D. and Torrie, J.H. (1984) Principles and Procedures of Statistics: A Biometrical Approach. 2nd McGraw Hill Book Co., Singapore.

Sürek, H.and Beser, N. (2003). Correlation and path coefficient analysis for some yield related traits in rice (*Oryza sativa* L.) under Thrace. Turk. J. Agric. Sci. 27:77-83 p.

Swamy B. P., Robin S., Satish B. Verulkar., Shalabh Dixit., and Amelia H (2013).Genetic, Physiological, and Gene expression analyses reveal that multiple QTL enhance yield of rice mega-variety IR64 under drought https://doi.org/10.1371/journal.pone.0062795.

Syed, E., and Khaliq, T. (2008). Quantitative inheritance of some physiological traits for spring wheat under two different population densities. Pakistan Journal of Botany 40(2): 581-587 p.

Tahir, H. Jillani, G. and Iqbal, M. Z. (1988). Integrated use of Organic and inorganic N fertilizers in rice wheat cropping system. Pakistan Journal of Soil Science 3:19 – 23 p.

Terdoo, F. Feola, G. (2016). The Vulnerability of Rice Value Chains in Sub-Saharan Africa: A review. Climate, 4(3):47. Available at SSRN: https://ssrn.com/abstract=3270886.

Tiawari, D. K.,Pandey,P., Singh, R. K., Singh, S. P. and Singh, S. B. (2011). Genotype x environment interaction and stability analysis in elite clones of sugarcane (saccharrum officinalis L.). International Journal of Plant Breeding and Genetics 5(1): 93 – 98 p.

Tripathy, K. K. Warrier, R. Govila, O. P. Ahuja, V. and Mehra, P. (2011). Biology of rice (*Oryza sativa* L.). New Delhi. http://wwwigmoris.nic.in.

Troare, K. (2005). Characterization of novel rice germplasm from West Africa and genetic marker association with rice cooking quality, Texas, USA: Texas A and M University, PhD thesis.

Ulbricht, C., Abrams, T.R., and Brigham, A. (2010). An Evidence-Based Systematic Review of Rosemary (Rosmarinus officinalis) by the Natural Standard Research Collaboration. Journal of Dietary Supplements 7(4):351-413 p.

Umadevi, M. ,Pushpa, R., Sampathkumar. K. P. Debit, B. (2012). Rice traditional medicinal plant in India Journal of pharmacognosy and phyto-chemistry. 2278-413.

Vanaja, T. and Babu, C. L. (2004). Variability in grain quality attributes of high yielding rice varieties (*Oryza sativa* L.) of diverse origin. Journal of Tropical Agriculture 44 (1-2): 61-63 p.

Vaughan D.A., Morishima, H., Kadowaki, K. (2003). Diversity in the Oryza genus. Current opinion in Plant Biology.6:139-146 p.

WARDA, 2007. Descriptors for wild and cultivated rice (Oryza spp.).

World Bank Projections (1994-95): http://www.fao.org/docrep/003/x6905e/x6905e04.htm.

Wyte, R.O. (1972). 'The Gramineae, wild and cultivated plants of monsoonal and equatorial Asia Southeast Asia'. Asian Perspect. 15: 127-15 p.

Xing, Y. and Zhang, Q. (2010).Genetic and Molecular basis of rice yield. Annual Review of Plant Biology 61(1): 11 – 22 p.

Yadav, P. Rangare, N. R. Anurag, P. J. and Chaurasia, A. K. (2008). Quantitative analysis of rice (*Oryza Sativa* L.) in Allahabad agro climate zone. Journal of Rice Research 3: 1 – 15 p.

Yadav, R. B. Malik, S. and Yadav, B. S. (2016). Physio-chemical, pasting, cooking and textual quality characteristics of some Basmati and non-Basmati rice varieties grow in India. International Journal of Agricultural Technology 12(4): 675-692 p. http://www.ijataatsea.com.

Yau, N.J.N and Liu, T.T. (1999). Instrumental and sensory analysis of volatile aroma of cooked rice. Journal of Sensory studies. 14(2), 209-233 p.

Yoshida, S. (1981). Fundamentals of rice crop science. International Rice Research Institute, Los Banos, Laguna, Philippines, 269.

Zibaee, A. (2013). Rice: Importance and Future. DOI: 10.4172/jrr.1000e10.