Performance of Some Selected Rice Cultivars for Yield and Grain Quality

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ABSTRACT

Rice is an important crop in Eastern Africa and it is often ranked after maize, sorghum and wheat. Rice is mostly grown by small scale farmers as commercial and food crop; however rice yield per hectare is low (<3.6 t/ha) because smallholder farmers rely on local rice cultivars with low yield potential, poor grain quality, highly susceptible to bacterial leaf blight and rice blast. Thus, there is need to improve locally adapted rice cultivars for high yield and desirable grain qualities. The objective of this study was to contribute to increased rice productivity through the development of improved, locally adapted rice varieties with high yield potential, earliness and high grain quality. Thirty one genotypes, comprising of parental lines and F_1 progenies were generated from crosses between three male indica parents and seven japonica females using North Carolina Design II mating system 14 $F_{2.3}$. Segregating populations were evaluated during rainy season 2016/2017 at Mwea Research Station of KARLO in a randomized complete block design with three replications. The genotypes were scored for grain yield, grain quality and several other agronomic traits. Data were 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 cross of 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.

Keywords: Grain Quality, Aroma, Yield, *Oryza sativa*

INTRODUCTION

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 or unacceptable to consumers (Yau and Liu, 1999). 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.

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 remain 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 (Demont *et al*., 2017). Hybrids must have high grain quality 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. 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). The rice yield in South Sudan is very low (0.6 t/ ha) compared to a minimum of 2.13 t/ha produced in the Sub-Saharan region (Michael *et al.,* 2007). Rural and urban consumption of rice in South Sudan is estimated at 3.0 kg and 10.92 kg per person per year respectively (Dorosh and Rashid, 2015), compared to 45 kg per-capita consumption in Sub-Saharan Africa (Muthayya *et al.,* 2014).The per-capita consumption in South Sudan is much lower than in most of the East African countries because the supply of locally produced rice is low. This is because the few smallholder farmers in South Sudan grow landraces that are low yielding, late maturing and of poor grain quality (FAO, 2013).

The demand for rice has been increasing at a rate of 12 % since 2008 in Eastern Africa. However, local production is very low to meet the demand of the increasing population (Ngotho, 2017). The demand gap is created because smallholder farmers in the rice growing regions of Kenya and other East African countries prefer growing lowland rice to upland rice. Therefore, improving the yield potential, earliness and grain quality of upland rice varieties through hybridization of indica and japonica rice may be a more sustainable way of increasing rice productivity in eastern Africa. The objective of this study was to evaluate upland rice cultivars for grain quality traits and yield.

MATERIALS AND METHODS

Site location

The experiment was conducted at Kenya Agricultural Research and Livestock Organization (KARLO), Research Centre in Kirinyaga County. The site lies at 00º 37' S latitude and 37º 20' E longitude with an elevation of 1159 m above sea level (masl). The rainfall at the site ranges between 500 mm and 1250 mm divided into long rains (March – June) with an average of 450 mm. However, short rains start in Mid-October end in December with an average of 350 mm, and total average rainfall of approximately 850 mm during the cropping seasons. The rainfall is characterized by uneven distribution in total amounts, time and space. The temperature ranges from 15.6º C to 28.6º C with a mean of about 22ºC. The soil is a nitosol, which is deep, well drained dusky-red to dark reddish-brown, friable clay with low fertility (KARI, 2000).

Plant materials

The genotypes evaluated comprised of 7 parents and 7 $F_{2.3}$ populations (Table 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 were included in the crossing block of six males and six females 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.

Experimental design and procedure

The three male indica and seven female japonica parents were grown in hybridization nursery of about $5m^2$ x $5m^2$ at Industrial Crop Research Cenre. The cultivars were crossed using North Carolina II mating design system. The parents were planted in buckets at the hybridization nursery in Mwea Research Station to produce F1 seeds that were subsequently selfed to produce F2 population during the short rain season between September and December 2014. The outstanding F2 populations were selected using pedigree breeding method and evaluated at Mwea Research Experimental Farm during the cropping season of 20016 to generate the $F_{2:3}$ rice families.

The 7 parents and $FR_{2:3}$ populations were planted in Randomized Complete Block Design with three replications at Mwea Research Experimental Farm. The seeds were shown using direct seeding method with an inter-row spacing of 20cm and inter-row spacing of 20cm with two seeds per hill. Gapping and thinning was done when the seedlings were 2-3 weeks old. One seedling per hill was left to ensure uniform plant density. Hand weeding was done at 20, 40 and 60 days after planting. DAP fertilizer (18:46:0) was applied during planting at a rate of 50 kg N ha^{-1} and 40 kg P ha^{-1}. First top dressing was carried out at active tillering using NPK (17:17:17) fertilizer applied at the rate of 120 kg N ha^{-1}, 30 kg $^{-1}$ and 50 kg K ha $^{-1}$ calcium ammonium nitrates (CAN) fertilizer was applied at panicle initiation stage at the rate of 100 kg N ha^{-1}. Pesticide (Duduthrin 1.75 EC, Lambda-cyhalothrin 17.5 g/L) was applied every two weeks to control stem borer, fall army worm and leaf hoppers at the rate of 50 ml/20 L of water.

Table1. Rice genotypes grown in Kenya with different attributes screened for yield and grain quality.

Variety	Source	Variety	Characteristics
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
DouradoxxKuchum	KARLO-Mwea	$F_{2:3}$ progeny	Tolerance to blast and RYMV + high yielding with good cooking quality
K1-99 xxKomboka	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 xxKuchum	KARLO-Mwea	$F_{2:3}$ progeny	Early maturity, long grains and blast tolerant + High yielding potential with good cooking quality
Nerica 10 xxMwur 4	KARLO-Mwea	$F_{2:3}$ progeny	Early maturity, long grains and blast tolerant + High yielding
Nerica 2 xx Basmati 370	KARLO-Mwea	$F_{2:3}$ progeny	Non aromatic and drought tolerant + Long slender grain, superior aromatic with good cooking quality
Nerica 3 xx Basmati 370	KARLO-Mwea	$F_{2:3}$ progeny	Long slender grain, high yielding, superior aromatic rice with good cooking quality
Nerica 1 xxMwur 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

Data collection of agronomic and yield traits

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

Determination of physical grain quality was carried out by randomly sampling 10 grains 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).

Sample of 2g milled rice kernels were measured from each of the rice samples and placed 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.

Data analysis

GenStat 15th edition statistical package was used to determine analysis of variance (ANOVA) among the genotypes. 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.

RESULTS

The results of analysis of variance for the 14 genotypes revealed wide range of variability for most of the traits across the seasons (Table 2). The mean squares due to genotypes for all the traits were highly significant at levels (P ≤ 0.01) and significant at (P ≤ 0.05) except for panicle length across all the seasons. Genotypes were significant at level (P ≤ 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 ≤ 0.05) in both seasons. The combined analysis data due to genotypes showed highly significant at level (P ≤ 0.01) for all traits except panicle length which was insignificant. Genotype x Season interactions were significant at level (P ≤ 0.01) for all the traits studied except plant length and number of spikelet per plant, while plant height was significant at level (P ≤ 0.05) (Table 2).

Table 2. Analysis of variance for agronomic traits at Mwea research station farm

SOV	DF	DF (50%)	DM	PH	PL	FL	NPT	NSP	NFG	NEG	TGW	GY
Rep	2	2.1	13.3	52.5	0.3	12.1	12.2	3.3	284.5	28.9	10.1	0.3
Genotype	13	119.4**	197.1**	65.1*	5.1	17.7**	113.0**	16.7**	814.7**	95.7**	13.2**	4.1**
Season	1	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	52.2**	41.8**	61.4*	2.5	10.2*	19.9	3.4	290.7**	85.3**	8.43*	0.8**
Residual	54	12.0	4.1	29.2	2.9	5.3	12.5	3.4	79.7	22.7	3.9	0.2

Define SOV, DF= degree of freedom, DF (50%)=days to 50% flowering, DM=Days to maturity, PH=plant height, PL=panicle length, FL=flag leaf, NPT= number of productive tillers, NSP= number of spikelet per panicle, NFG= number of filled grains, NEG= number of empty grains, TGW=thousand grain weight, GY= grain yield

All the genotypes in the study showed significant difference in the number of days to 50% flowering across the seasons. The days to 50% flowering ranged from 104.8 days to 119.9 days. The generation of Kuchum (104.8 days) flowered earlier, while the generation of K1-99 x Komboka (129 days) was the last to flower across the seasons (Table 3). Days to maturity ranged from 127 days to 148 days. Genotypes Nerica 10 (127 days) and Nerica 1 showed early maturity, while K1-99 x Komboka (148 days) and Nerica 3 x Basmati 370 (143 days) was late maturing genotype (Table 3).

Plant height showed differences among genotypes at level of (P ≤ 0.01) significance across seasons. The heights varied from 93 cm to 102 cm among the genotypes with Nerica 2 x Basmati 370 (102 cm) and Basmati 370 (102 cm) the tallest genotypes, while Nerica 1 x Mwur 4 (92 cm) and Nerica 1 (93 cm) were the shortest (Table 3).All the genotypes showed no significance for panicle length across the seasons (Tables 3).The length of the flag leaf varied from 21 cm to 27 cm. The genotype with the longest flag leaf was Nerica 1 (27 cm) and Nerica 10 x Kuchum (27 cm), while Basmati 370 (21 cm) and Nerica 10 had the shortest flag leaf (Table 3).There was significant difference in the number of productive tillers in all the genotypes studied.

Number of productive tillers varied from 18.5 to 33.7 among the genotypes. Generation of Nerica 3 x Basmati 370 (33.7) has the largest number of productive tillers, and Nerica 1 (18.5) had the least numbers of productive tillers across the seasons (Tables 3).In the case of number of spikelets per panicle, there was variation among the genotypes varying from 9.5 cm to 16.2.cm Genotype Nerica 10 (16.2) had the greatest while genotype Kuchum (9.5) had lowest number of spikelet per panicle across seasons (Tables 3).

Number of filled grains per panicle showed differences among genotypes across the seasons. The filled grains varied from 98.3 to 138.8. The generation of Nerica 3 x Basmati 370 (138.8) presented the highest number of filled grains per panicle across the seasons, while genotype Dourado (98.3) was the least with number of filled grains (Table 3).

Differences among the genotypes were observed in 1000 grain weight across the seasons, the heaviest 1000 grain weight was recorded for Nerica 3 x Basmati 370) (23.6), genotype Dourado (19.5) had lightest number of 1000 grain weight (Table 3).All genotypes gave different yield performances across the seasons. Grain yield varied from 3.6 t ha^{-1} to 6.4 t ha^{-1}. Generation cross of Nerica 3 x Basmati 370 (6.4) had the highest grain yield in across the seasons .Genotype, Dourado produced the lowest grain yield across the seasons (Table 3).

Table 3**.** Yield and yield components for14 genotypes for yield and its components at Mwea research center 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 ≤ 0.01), *:significant at level (P ≤ 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}).

Grain quality

Length/width (L/W) ratio was used to classify rice grains with long, medium, long bold, intermediate, very long slender and very long medium grains. Thus, the L/W ratio ranged from 0.93 to 3.08. Genotype with the highest L/W ratio was Nerica 10*Mwur 4 (3.08 mm), and the one with lowest was Nerica 10 (0.73 mm).

Aroma was detected in most of the genotypes studied; the strongest aroma was detected in Basmati 370, while genotypes with moderate aroma were Nerica 1, Nerica 2*Basmati 370 and Nerica 3*Basmati 370. Genotypes Nerica 10 and K1-99*Komboka had no aroma (Table 4).

Phenotypic correlation

In the combined analysis, days to 50% flowering were strongly and positively correlated with 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 length of 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 = 0.40) and number of filled grains at (r = 0.41). One thousand 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 =0.20) 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 4. Mean 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			

GL, Grain Length; GW, Grain Weight: L/W, Length/Width

Table 5. Combined analyzed 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

DISCUSSION

The separation of genotypes, environment and their interactions provide a good understanding of different cultivars across the seasons. Seasonal genotype x environment interactions were significant ($P \leq 0.01$ and $P \leq 0.05$) for most of the traits in this study revealing that genotypes reacted differently for these traits in the two seasons .Therefore, this could explain the genetic variations observed in the genotypes used in this experiment. 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 variations for all characters studied in rice.

Genotypes showed wide range of genetic variability in relation to days to flowering from 106 to 119 days. 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.

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 genuine criteria for growing in areas with bimodal rainfall, and late flowering genotypes can be useful if genotypes flower near the end of rain season when soil moisture is still adequate (Kihupi, 1984).

There were variations in panicle length in the two seasons.. 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 in the two 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 were 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. The variation in flag leaf length across the rains could have been due to vegetative growth. Rice plants with long flag leaves have large surface area to intercept sun light and they can undertake increased 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 *et al*, (1994) who reported a higher direct effect of flag leaf area on grain yield.

There was a variation in number of tillers in the two seasons. 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. 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 with 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 displayed wide variability for number of filled grains per panicle. This study revealed that 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 variations for number of filled grains per panicle, number of filled grains contributed positively to grain yield. However, 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 capacity. 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 variations observed for panicle weight and thousand grain weight among the genotypes indicated that the genotypes were genetically diverse and that the variations were due to presence of inherent genetic differences among the genotypes. A similar result was reported by Akinwale *et al.* (2011) and Osman *et al.* (2012). 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 agree 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.

The height of the genotypes differed in the two season. The location was suitable and ideal locations for the growing of these genotypes, since they appeared to be well adapted to this location. 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 in increase in plant height. The results further revealed that rice plants with relatively short to intermediate height exhibited higher grain yields. This could be attributed to the favourable growing conditions at Mwea Research Centre characterized by good soils with retention capacity and high humidity.

Hussain *et al.* (2005) reported that water and soil conditions affect plant height in rice plants. Rice plants with short to intermediate height generally have higher harvest index. This could be due to or attributed to the supply of assimilates to developing grains. Tall rice plants like Dourado recorded low harvest index. This may be due to 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 types would be advantageous in relation to grain yield.

Highest grain yield was recorded in the generation's crosses of Nerica 3 x Basmati 370 and Nerica 2 x Basmati 370, while Dourado and Nerica 1 had the lowest gain yield. The variation in grain yield across the seasons could be due to favourable growing conditions characterized by good soils as well as ample 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. Since rice is produced and marketed according to grain size and shape, 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 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.

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.*, 2011). 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.

Aroma is an 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). This study has shown that aroma is heritable from one generation to another, and the intensity of aroma is affected by genetic as well as environment conditions. Therefore, 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 aroma may be further incorporated into these improved lines through back crossing method.

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 amongst the rice genotypes are important contributors to variation in grain yield. High significant treatment effect for most characters as obtained in this study indicate that the genotypes evaluated differed significantly in these characters. Dev *et al.* (2019) 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 (Ronghua *et al.* (2019).

Furthermore, rice yield was significantly reduced as a result of days to 50% flowering (heading) (r= -0.06) (Table 3.9). The findings are similar with work of Birhanu *et al*., (2017) 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.

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's 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 study has shown that Basmati 370 can be used for improvement of local cultivars

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