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Genotypic Performance of Kenyan Rice Cultivars for Grain Yield and Quality

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Abstract

Rice is the third most important staple food in Kenya after maize and wheat and it is mostly grown by small scale farmers both for food and cash under irrigated and rainfed production systems. In this study, fourteen $F_{2.3}$ segregating populations together with their parental lines, were evaluated during the long and short rainy seasons of 2016/2017 at the Mwea Research Station (KALRO) in a randomized complete block design of three replications for grain yield, quality and agronomic traits. There were significant differences among genotypes for all the traits studied. Genotypes, Nerica 1, Nerica 2 and Basmati-370 matured earliest, whereas genotype, Basmati-370 gave the highest grain yields in both seasons. The F_1 generations of crosses of Dourado x Nerica 3 and Mwur 4 x Nerica 3 had the highest positive Specific Combining Ability (SCA) gene effects for panicle length, days to flowering and grain yield. However in the $F_{2.3}$ generations, the progenies of Nerica 2 x Basmati-370 and Nerica 3 x Basmati-370 had the highest grain yields. Generations of Nerica 10 x Mwur 4 crosses, had the longest grains whereas the Basmati-370 genotype had the strongest aroma. Generations of NERICA 3 x Basmati 370 and NERICA 2 x Basmati 370 crosses were of mild aroma, but those of K1-99 x KOMBOKA and NERCA 10 were non aromatic. Grain yield was positively significantly correlated with number of productive tillers, number of filled grains and 1000 grain weight indicating that these traits could serve as secondary selection indices for yield. It is inferred that breeding rice cultivars with improved traits for grain yield, long grain and strong aroma would benefit from the utilization of parental and population germplasm identified in this study, in the pursuit of filling the current rice production deficit in the Kenyan consumer markets.

Keywords: oryza sativa, GCA, grain yield, grain quality, SCA

1. Introduction

Rice is the most widely grown and consumed cereal crop in the world followed by wheat and maize and it is the major food source for more than half of the world's population (IRRI, 2010). In Kenya, rice, is the most widely consumed staple after maize and wheat, though it is grown in lesser hectarage due to lack of reliable rainfall and irrigation facilities. Most rice is produced under both rainfed and irrigated farming systems with a small fraction being cultivated as upland rice. The irrigated areas under rice are 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 current rice production in Kenya varies between 43,000 to 80,000 MT, while consumption is well above 300,000 MT (during 2005 – 2010; MOA 2010). The demand for rice consumption has increased to 30.5 % creating a deficit of about 80% that is too high to meet through imports. The average production for consumer preferred aromatic varieties is at 5.5 tons/ha whereas that of non-aromatic ones is at 7 tons/ha under irrigation (MOA, 2014). The current rice cultivars in Kenya are grown at an altitude range of from 0 to 1700 meters above sea level with temperature range of 17^{o} C to 34^{o} C. The varieties grown 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: rain-fed upland cultivars include; Dourado Precoce, TGR-94, Nam Roo and the NERICA 1,4,10,11 (New Rice for Africa) whereas rain-fed lowland (swampy) zones varieties include; Jasmine-85, TGR-78, WABIS 675 and the popular Basmati variety known for its superior grain quality trait. Needless to say, rice yields have been declining over the years due to poor agronomic practices, poor quality seeds and low yielding varieties (MOA, 2010). Unlike most food crops, rice grain is eaten whole making it is sensory and grain quality properties a crucial determining factor of market prices (Yau and Liu, 1999) and Hossain et al., (2009). The two important consumer preferred grain qualities in Kenya, are aroma and long grains and since most introduced rice cultivars selected for aromatic traits originated from India (*O.indica*) and whereas those for long-grains originated from Indonesia (*O. japonica*), hybridization between the two groups, is likely produce cultivars that will sustain rice productivity in Kenya.

The objective of this study was to evaluate the performance of popular rice cultivars in Kenya and their segregating progenies for grain yield and yield components potential and their grain quality characteristics as a basis for recommendations to farmers, consumers and researchers.

2. Materials and Methods

2.1 Site Location

The experiment was conducted at Kenya Agricultural Research and Livestock Organization (KARLO), Research center in Kirinyaga County. The site lies at 00 ^{o} 37' S latitude and 37^{o} 20' E longitude with an elevation of 1159 m above sea level (masl). The rainfall at the site ranges between 500 mm to 1250 mm with long rains falling between March - June with an average of 450 mm whereas short rains start in Mid-October to December with an average of

350 mm. Rainfall in both seasons is characterized by uneven distribution with temperatures ranging from 15.6º C to 28.6º C and with a mean of about 22ºC. The soil is well drained, dusky-red to dark reddish-brown nitosol, of friable clay with low fertility (KARI, 2000).

2.2 *Plant Materials*

Table 1, shows the origin, agronomic and quality characteristics of the seven parental genotypes and their resultant F2.3 populations generation of crosses that were evaluated. The $F_{2.3}$ populations had been developed earlier in 2014 at Mwea Rice Research Station using North Carolina 1 mating design without reciprocals Method 4, (Griffing, 1956). As shown in Table1, the parental lines were selected for earliness, quality, drought tolerance, high yield and disease tolerance.

2.3 Measurements of Agronomic, Yield related Traits and Data Analysis

Data for agronomic and yield traits were collected according to the procedure outlined in Standard Evaluation System (SES) for rice (IRRI, 2013). The quantitative and qualitative data was collected at appropriate stages of crop development namely at the vegetative, flowering, maturity and harvesting stage.

i. Days of 50% flowering (FL) was calculated visually by counting the number of days from showing of the plants in each specific plot. The scales was 1 extremely early, 3 was early, 5 was average and 7 was late.

ii. Days to maturity (DM) were counted from the day of planting for each genotype in each replication and recorded when 80% of the plants in a plot reached maturity.

iii. A meter ruler was used to measure the height of the plant (PH) from the soil surface to the top of the highest panicle (awns omitted). Two rows in the centre were used to record the whole numerals.

iv. A random sample of plants were used to measure panicle length (PL), the distance was measure from the base of the panicle and its tip in centimeter.

v. The number of panicles per plant from a sample of ten (10) plants per hill was counted to determine the number of productive tillers (NPT).

vi. The fertile spikelet (NSP) was identified in accordance with Laffite et al., (2003). From each plot, ten panicles were randomly chosen. Spikelet fertility was scored as; (1) highly fertile (>90%), (3) fertile (75-89%), (5) partly sterile (50-74%) and (7) highly sterile (0%).

vii. Number of grains per panicle (NFG) was calculated at random from the plot's chosen panicles, and the filled panicles were separated using a machine that separates seeds. Manual counting was done to determine how many full and empty grains were present.

viii. One thousands seed weight (TGW) was calculated by counting each individual entire grain of 100well developed grains. The samples were weighted using an electric balance after being numbered and dried to a moisture content of 14%. The resulting weight was then multiplied by 10 to equal 1000 grains.

ix. Ten random chosen plants from each plot were used to calculate the grain yield (GY) per plant. The grain were manually harvested, hand threshed, and dried until it had 14% of moisture content. A moisture meter was used to calculate the moisture content. Using a machine balance, the grain was weight in kilograms. Grain yield per plant in t/ha-1 was estimated using the mean grain weight from the 10 plants.

2.4 Grain Quality

A vernier caliper was used to measure the diameters of 10 gains selected at random from the sample (Rickman et al., 2006). Ten grains on average were noted. Vanangamudi et al., (1987) scale was used to categorized grain width as slender (below 2mm), semi long (2 – 2.4 mm), semi spherical (2.4 – 3mm), and spherical (above 3mm), and seed length as short (below 7.5 mm), medium (7.5 – 9 mm), long (9 – 10 mm) and very long (above 10 mm).

Each genotype received a sample of 2g milled rice kernels, which were then put in a petri plate. The sample was then steeped for around an hour at room temperature in a 10 ml solution of 1.7% KOH. Four farmers and four students were asked to grade the samples of soaked rice on a scale of 1 to 4. With (1) representing no scene, (2) little aroma, (3) moderate aroma and (4) strong aroma.

Using the genetic designs in R (AGD-R) version 3.0, the analysis of variances to assess the differences between genotypes was carried out using (Gregorio et al., 2015). The least significant differences test (LSD) was used to compare the treatment means at a P value of 0.05. As demonstrated above, Pearson's correlation coefficients were used to calculate simple linear correlation (Benesty et al., 2009) as follows.

$$\mathbf{r} = \frac{\mathbf{n}(\sum \mathbf{xy}) - (\sum \mathbf{x})(\sum \mathbf{y})}{\sqrt{[\mathbf{n}\sum \mathbf{x}^2 - (\sum \mathbf{x})^2][\mathbf{n}\sum \mathbf{y}^2 - (\sum \mathbf{y})^2]}}$$

r = Pearson Coefficient

n= number of variables

$\sum xy$ = sum of products of the variables

$\sum x$ = sum of the x variable

$\sum y$= sum of the y variable

$\sum x^2$ = sum of the squared x variables

$\sum y^2$ = sum of the squared y variables

2.5 Combining Ability

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:

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

Where,

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

m = is the hybrids overall average

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

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

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

1K = effect of the k^{th} replication

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

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

j = is the number of male parents (1, 2 …m)

k = is the number of replications (1, 2….r)

2.6 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;

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

Where the variance components for GCA and SCA, as predicted from Griffing's approach model 1, are $2\sigma^2$GCA and σ^2SCA, respectively (fixed effects). Ratios that are near to one show that additive effects play a significant role in the inheritance of the trait, whereas ratios that are close to zero show that dominance and epistasis effect play a significant role.

3. Results

3.1 ANOVA of 14 Parental and Segregating Populations Grown in the Field for Two Seasons

The findings of the analysis of variance for the 14 genotypes over the course of two seasons revealed that majority of the features were very variable (Table 2). With the exception of panicle length (PL) throughout all seasons, all variables genotype based mean squares were highly significant at levels (P 0.01) and significant at (P 0.05). With the exception of PL, FL, and TGW quantity, all attributes were significantly influence by the seasons (P 0.01). For all the characteristics examined, genotypes x season interactions were significant at level (P 0.01) with the exception of PL, NPT, and NSP (Tabl2 2).

Table 3 shows that the means of all traits evaluated were highly significant at both (($P \leq 0.01$

and $P \leq 0.05$) except for PL. Nerica 3 x Basmati-370, though not significantly different from Nerica 2 x Basmati-370 gave the highest grain yields (Table 3). All the traits had low CV values meaning there was low environmental variation for their estimation except for NPT and NSP that were slightly higher.

3.2 GCA and SCA Estimates of Parental Lines and Their F1 Crosses

The GCA mean squares were highly significant for the interaction between male x female variance except for panicle length (PL), number of spikelet's (NSP) and TGW (Table 4). But the GCA mean square variance for male lines and to some extent female lines was much larger than that of the male x female interaction effects an indication that GCA variance values were likely to be higher than specific combining ability (SCA) variance values. The additive gene effects were higher than dominance gene effects and the additive dominance ratios values were all above 1 for all the traits except for grain yield (GY) (Table 4) an indication that additive gene variance contributed most to their inheritance rather than dominance gene variance. Male lines contributed most of the additive gene effects than female lines as indicated in Table 4.

Table 5 shows the specific combining ability (SCA) sum of squares for the 21 crosses. Six crosses gave positively highly significant SCA effects. These were as follows; Dourado x Nerica 3 had positive SCA effects for PL, FL and NSP; Mwur 4 x Nerica 3 had positive effects for PH, PL and GY; Komboka x Nerica 2 had positive effects for DM and NPT; Dourado x Nerica 1 had positive effects for PH, FL, TGW and GY; Dourado x Mwur 4, had positive effects for NFG and Komboka x Basmati 370 had positive effects for PH, TGW and GY (Table 5). Three of these, namely, Mwur 4 x Nerica 3, Dourado x Nerica 1 and Komboka x Basmati 370 contributed direct positive allelic effects for grain yield whereas Dourado x Mwur 4, Komboka x Nerica 2 and Dourado x Nerica 3, contributed positive allelic effects for indirect yield components. The cross, Dourado x Nerica 1 appears to be the one that inherited most additive gene effects as indicated the high number of traits with positive SCA effects. As parental lines with high GCA allelic effects for yield determining genes, Nerica 3, Nerica 1 and Basmati-370 appear to have effectively transmitted their additive genetic effects despite combining with poor performing genotypes such as Mwur4 and Komboka (Table 5).

SCA effects were highly negative in the crosses, Dourado x Kuchum for PL and NPT and also in the cross, Mwur4 x Nerica10 for GY. Other crosses that gave negative but non-significant SCA effects included; Mwur4 x Mwur2 , Komboka x Mwur 4, Mwur 4 x Nerica 1 and Mwur 4 X Nerica 10. The progenies for these crosses are likely to be poor performers under field conditions with Dourado x Basmati 370 being the lowest.

3.3 Phenotypic Correlation Coefficients

In the combined ANOVA (Table 6), days to 50% flowering (FL) were strongly significantly positively correlated with days to heading (DH)) at ($r = 0.76$). Days to maturity (DM) was significantly positively correlated with days to heading (DH) at ($r = 0.45$). Plant height (PH) was also significantly positively correlated with days to maturity (DM) at ($r = 0.24$). Similarly, number of productive tillers (NPT) was positively correlated with days to maturity (DM) at (r

= 0.23), plant height (PH) at (0.37), number of filled grains (NFG) and also with number of productive tillers (NPT) at (r = 0.76). Grain yield (GY) had a strong positive association with NPT (r=0.79) and with NFG (r=0.80) but a negative significant association (r=-0.55) with number of empty grains per plant (NEG). GY had a low but significant correlation with DM (r=0.21) but was not significantly associated with days to 50% flowering or with days to heading. The number of empty grains (NEG) was negatively correlated with number of productive tillers (NPT) (r =- 0.40) and number of filled grains (NFG) at (r = 0.41) but NFG was significantly positively correlated with NPT at (r=0.76) (Table 6).

3.4 Grain Quality Characteristics

Table 7, shows the means of the grain characteristics. Length/width (L/W) ratio was used to classify rice grains into long medium, long bold, intermediate, very long slender and very long medium grains. As shown in the table, the L/W ratio ranged from 0.93 to 3.08. The genotype with the highest L/W ratio was Nerica 10 x Mwur 4 (3.08 mm), and the one with lowest was Nerica 10 (0.73 mm) (Table 7).

Aroma was detected in most of the genotypes studied with the strongest aroma detected in Basmati 370, whereas genotypes, Nerica 1, Nerica 2*Basmati 370 and Nerica 3*Basmati 370 had moderate aroma were but for genotypes, Nerica 10 and K1-99*Komboka no or little aroma was detected (Table 7).

4. Discussion

4.1 Grain Yield and Days to Flowering Variation

Analysis of variance showed significant differences for all traits studied except thousand grain weight an indication of genetic variability among the genotype (Table 2). As suggested by Oyung et al., (2012) the presence of the large amount of genetic variation observed in these trials might have been due to the diversity of materials as well as to environmental influence. However, the significant season x genotype interactions is an indication firstly of a significant genetic variance component and secondly of an inference that genotypes reacted differently to environmental effects and are likely to be adapted to specific environments. This fact is supported by studies of Akinwale et al., (2011) and Singh et al., (2011) who reported significant genotypic variation for similar traits in rice. Additive gene effects were higher than dominance gene effects for all traits measured except for grain yield and to some extent in number of filled grains. Additive/ dominance ratio was above 1 for all traits except for grain yield again underscoring the fact that additive gene action was responsible for the transmission of genes from the parents to their progenies

Genotypes varied greatly, notably in terms of the number of days till blooming, which ranged from 106 to 119 days (Table 3). Though it is likely that a significant phenotypic variance exists among genotypes for days to flowering, the variation in rainfall distribution prior to flowering could have had an effect albeit a smaller one. Indeed, as reported by Sabouri and Nahvi, (2009) in rice, days to 50% blooming are influenced by environmental influences as well as genetic one. In order to boost crop production from two to three per year, farmers may select the genotypes Nerica 2 x Basmati 370, Dourado, and Nerica 10. These genotypes had the greatest substantially shorter period to blooming. Medium and late flowering genotypes are also likely to find a niche in agroecological zones where rainfall is bimodal and there is still adequate soil moisture at the end of the season.

4.2 Panicle Length, Flag Leaf and Tillering Variation

There were variations in panicle length in the two seasons. The longest panicles were found in the genotypes Basmati 370 and Nerica 10 x Kuchum, whereas the smallest panicles were found in Dourado and Dourado x Kuchum. The two season's differences in panicle length could have been caused by regular irrigation regimes at the Mwea Rice Research Station resulting in high vegetative growth. The quantity of grains that can be accommodated in a rice panicle length is determined by its length and as the results demonstrated, the genotypes with longer panicles also contained more grains than those with shorter panicles (Efisue et al., 2014). The largest flag leaf lengths were found in crosses of Nerica 10 x Kuchum and Nerica 1, whereas Komboka and Basmati 370 had the smallest lengths. Although phenotypic diversity is obvious, the difference in flag leaf length may have been produced by vegetative growth brought on by the rain. Long flag leaf rice plants may intercept more sunlight, which increases photosynthetic activity and produce more assimilates for grain filling, resulting in greater grain weight and better grain production (Bharali et al., 1994). The genotypes, Nerica 10 x Kuchum and Nerica that are reported in this investigation fit this description. The amount of productive tillers varies between the two seasons. The most prolific tillers were found in generations of crosses between Nerica 3 x Basmati 370 and Nerica 2 x Basmati 370, whereas the least productive tillers were found in generation of crosses between Nerica 1 x Dourado. For the cultivation of commercial grains, rice tillering ability is an essential agronomic characteristic (Ibrahim, 1990 and Zahid et al., al 2005). As reported by these authors, effective tillering is the most reliable trait in selecting rice genotypes for higher grain yield. Tillering plays a vital role in determining not only grain yield but also the number of panicles per plant and the number of filled grains. In this study, the genotypes that were high yielding were also the ones that produced most tillers and most filled grains as shown by the strong positive significant phenotypic correlations between GY and these two traits (r-079; r=0.76, Table 6). Equally, Babu et al., (2012) also reported that the number of filled grains contributed positively to grain yield.

Most genotypes exhibited a typical quantity of grains per panicle. The fullest grains per panicle were produced by generations of the Nerica 3 x Basmati 370 and Nerica 2 x Basmati 370 hybrids (Table 5). As also shown by Luzi-Kihupi (1998) rice plants with larger panicles tended also to have higher grain filling capacity.

4.3 Genetic Variance for Diverse Traits

Phenotypic variation observed for panicle weight and thousand grain weights among the genotypes studied here, indicated that this was more due to their genetic variances than due to the environmental variance. Akinwale et al., (2011) and Osman et al., (2012), suggested that genotypes with larger number of panicles per plant and higher number of filled grains per panicle, despite having lower thousand grain weight, produced higher grain yields. Their findings agree with the results reported by Laza et al., (2004) who concluded that number of productive tillers, number of panicles per plant and numbers of filled grains were the most important yield components in rice. In rice, shorter or dwarf cultivars are preferred and tend to have higher harvest index than taller ones (Hussain et al., 2005). The results reported here agree with this observation as genotypes which were relatively shorter to intermediate in height gave higher grain yields than taller ones. Taller genotypes such as Dourado recorded lower harvest index probably due to the utilization of assimilates during the vegetative growth rather than during seed formation and grain filling. Shorter plants are associated with increased lodging resistance and higher grain yields in rice (Yoshida, 1981) and therefore selection of shorter to intermediate plant types would be advantageous to selection for grain yield. The generation of crosses between Nerica 3 x Basmati 370, Nerica 2 x Basmati 370, and Basmati 370 had the largest grain yield, whereas Dourado x Nerica 1 had the lowest grain yield. These trials were conducted for only two rainy seasons and it would be prudent therefore to include more replications and locations in order to deduce the effect of the genetic variance against that of the environment. Given the good growing circumstances of fertile soils and well distributed rainfall as noted by Xing and Zhang (2010), it is possible that the variance in grain output between the two seasons was caused by these factors. The genotypes, Nerica 3 x Basmati 370, Nerica 2 x Basmati 370, and Basmati 370 consistently retained greater yields throughout the course of the two seasons, indicating a wider adaptation to environmental conditions as shown by the highly significant, season – environment interaction.

4.4 GCA/SCA for Parental Lines and Generation of Crosses

Analysis of GCA/SCA variances showed that the nature of gene action was additive due to the high magnitude of fixable genetic component for days to maturity, plant height, panicle length, flag leaf, number of spikelets 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 differ with those of Sathya and Jebaraj (2015) who reported that dominance of the non-additive gene action plays a part in the inheritance of rice agronomic traits. But other authors (Chakraborty et al., 2009; and Vivekanandan, 2013) concur with the findings here that additive gene action is the predominant inherent factor. Dominance or non-additive gene effects seem to be of lesser importance in the inheritance of rice agronomic and yield traits (Muhammed et al., 2010 and Hasan et al., 2015).

The generation of crosses of Mwur 4 x Nerica 3, Dourado x Nerica 1 and Komboka x Basmati 370 were good specific combiners for grain yield an indication that crossing high GCA x high GCA parental combinations is likely to result into additive x additive variance in their hybrids which is fixable and predictable in subsequent generations (Sandhykishore et al., 2011). Negative SCA effects for grain yield was recorded in hybrids (Mwur 4 x Nerica 10) suggesting that one of parents was of low yield potential. Hybridizing low GCA parent with high GCA parent such as the case with, Mwur 4 x Nerica 10 might produce hybrids with high grain yield potential because of interaction between positive alleles in the good combiner and negative alleles in the poorer one (Chakraborty et al., 2009), but in subsequent generations, these hybrids are likely to produce transgressive segregants with both additive and non-additive genetic effects. However, because of the presence of non-additive genetic variance, this would result into yield reduction and therefore their grain yields might not be sustained in the long term. This study showed that the parents with high GCA estimates were not always the best general combiners. The results also indicated that parents with high GCA effects (Basmati 370, Nerica 2 and Nerica 3) were the best general combiners for certain specific traits, but none of these parents or the crosses arising from them resulted into high SGA variance as also reported by Chakraborty et al., 2009 and Malembe et al., 2017.

4.5 Phenotypic Correlations Among Traits and Grain Quality Characteristics

Grain yield had a small positive, significant association with thousand grain weight (r=0.27), plant height (r=0.32) and to days to maturity (r=0.21) but was strongly significantly positively associated with the number of filled grains (r=0.80) and the number of productive tillers (r=0.79), as expected. Grain yield was negatively significantly correlated with the number of empty grains per panicle (r= -0.55) (Table 6) again as would be expected.

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 important in the classification of grain shape. In many cases, long and slender rice grains are mostly preferred by many consumers and such grains normally fetch higher prices at international market ((Takoradi (2008; Singh et al., 2010).

All the genotypes in Table 7, showed an L/W ratio of between 2.1 and 3.0 except for 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. Yadav et al., (2016) studied physio-chemical, cooking, pasting and textual properties of Indian Basmati and non-Basmati rice varieties and reported a length to width ratio of more than 3.0 for Basmati grains which was significantly higher than non-Basmati grains.

Generation of crosses of Nerica 3 x Basmati 370 and Nerica 10 x Mwur 4 had the longest grain. The physical quality attributes shown here by Nerica 1 x Mwur 4 and Nerica 10 x Mwur 4 present breeding programs with the opportunity to improve grain quality of local rice cultivars.

Aroma is an important quality trait that influences the eating qualities and consumer preference of many rice varieties. In this study, Basmati- 370 had the strongest aroma, and as such should be incorporated as a parental line in any hybridization program as suggested by Kimani et al., (2013). It appears therefore that future rice improvement programs in Kenya must give priority to breeding not only for quantitative traits such as high grain yields, but also target to introgress grain quality traits such as length and aroma through conventional back-crossing or molecular marker assisted backcrossing.

5. Conclusion

Parental lines**,** Basmati 370, Nerica 2 and Nerica 3 gave the highest grain yields. Generations of crosses of Nerica 3 x Basmati 370 and Nerica 2 x Basmati370 consistently maintained high yield across the seasons. Additive gene action was the most important genetic variance governing the inheritance of most of the traits studied here. Generations of crosses of Mwur 4 x Nerica 3, Dourado x Nerica1, and Komboka x Basmati 370 had the highest significant SCA genetic effects and the highest grain yield potential. Generation of crosses of Basmati 370, Nerica 2 x Basmati 370 and Nerica 3 x Basmati 370 had the highest physical grain characteristics whereas Basmati-370 had the strongest aroma. Hybridization of locally adapted rice cultivars with Basmati-370 as one of the parental lines is likely to yield desirable rice cultivars for the consumer market.

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Table 1. Popular rice genotypes grown in Kenya and their $F_{2.3}$ populations with diverse attributes for yield and grain quality

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
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

Table 2. Analysis of variance of parental and segregating genotypes for agronomic traits at Mwea Rice Research Station during 2016/2017 rainy seasons

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	10.178*	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

Key: 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

Table 3. Means of Yield and yield components of the parental and segregating genotypes evaluated at Mwea Rice Research Station during 2016/2017 rainy seasons

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}).

Table 4. Analysis of variance for General Combining Ability (GCA) 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

Key:*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: Gra

Table 5. Specific Combining Ability (SCA) of the 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**

Key;*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})

Table 6. Phenotypic correlation coefficients of agronomic traits in the parental and segregating genotypes for the 2016/2017 rainy 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*	-

Key:* 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 7. Means of grain length, width and quality characteristics measured in the parental and segregating 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			