Screening Upland Rice Genotypes For Grain Yield And Grain Quality In Kenya

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ABSTRACT

Smallholder farmers in Kenya grow local rice cultivars that have low yield potential and poor culinary qualities. Therefore, urban consumers prefer imported rice. The imported rice is expensive and unaffordable to the rural poor. Therefore, improving the yield potential and grain qualities of the local cultivars will increase their consumption and competitiveness in the local market. The objective of this study was to improve the yield potential and grain quality of upland rice cultivars in Kenya. Seven $F_{2.3}$ families were selected from 16 segregating rice populations and evaluated for two seasons. The physical quality characters determined were grain length grain shape while the chemical and cooking qualities were alkali spreading value, gelatinization temperature, gel consistency, aroma, and cooking time. The data for yield and grain quality was subjected to analysis of variance using GENSTAT 15th edition. The results showed that the $F_{2.3}$ families of NERICA 4 x MWUR 4, NERICA 4 x NERICA 1 and NERICA 10 x KUCHUM exhibited slender grain shape while NERICA 4 x MWUR 4, NERICA 4 x NERICA 1 and WAB-56-104 x NERICA 4 had soft cooked texture and recorded low gelatinization temperatures of 55 to 69°C and cooked fast in 22.3 to 23.3 minutes. The $F_{2.3}$ families of WAB-56-104 x NERICA 4, NERICA 4 x MWUR 4, MWUR 4 x NERICA 4 and CG 14 x NERICA 10 had mild aroma while NERICA 4 x NERICA 1, NERICA 13 x K45 and NERICA 10 x KUCHUM were non-aromatic. Therefore, the $F_{2.3}$ families of MWUR 4 x NERICA 4, NERICA 4 x NERICA 1 and WAB-56-104 x NERICA 4 had high yield potential and exhibited better cooking and physico-chemical qualities. However, the check variety Basmati 370 was outstanding for physical grain quality and aroma compared to the non-Basmati rice genotypes suggesting that Basmati 370 has implication for future breeding. However, there is need to advance these $F_{2.3}$ families to F_6 or F_7 for further selection in order to ascertain their yield potential and culinary qualities.

Key words: Aroma, correlation, physico-chemical quality, grain quality, grain yield, *Oryza sativa*

1. INTRODUCTION

Rice (*Oryza sativa*) is the second most important food crop 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). In Kenya, annual rice production was estimated at 140,000 metric t against a demand of 540,000 metric t (Ngotho, 2017). This huge gap was fulfilled through imports from Pakistan, China, India and Vietnam (MoA, 2014). The demand gap is created because smallholder farmers in Kenya prefer growing lowland rice to upland rice. Upland rice varieties are marginally practiced because they have low yield potential and poor cooking and eating characteristics (Kimani, 2010). Therefore, it's important to identify outstanding rice varieties through characterization of the upland rice genotypes for direct improvement of productivity and grain quality of local rice cultivars grown by smallholder farmers. A preferred rice variety should not only have good agronomic performance but also high grain quality that is widely acceptable to farmers, millers and consumers (Fofana *et al.*, 2011). 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).

Previous studies suggested that aromatic and long rice grains are highly preferred and fetch premium price at the international market (Dela Cruz et al., 2002). The cooking and eating qualities of rice can be influenced by aroma, amount of amylose content, gel consistency and gelatinization temperature (Dela Cruz et al., 2002). Juliano (1993) reported a positive and significant association between gelatinization temperature and cooking time, but gelatinization temperature is negatively correlated with the texture of cooked rice. Rice varieties with higher gelatinization temperature normally have low amylose content (Dela Cruz and Khush, 2000). To increase adoption and consumption of a rice variety, rice breeders should take into consideration the yield potential and grain quality when developing new rice varieties for commercial production (Dela Cruz and Khush, 2000). The objective of this study was to improve the yield potential and grain quality of upland rice cultivars in Kenya.

2. MATERIALS AND METHODS

2.1 SITE DESCRIPTION

The experiment was conducted during the cropping season of 2016 and 2017 at the Industrial Crops Research Centre of the Kenya Agricultural and Livestock Research Organization. The research station is located in Mwea Division, Kirinyaga County, Kenya. The site lies on a latitude 0 37'S and longitude 37 20'E on an elevation of 1159 m above sea level. The soil type is nitosol with a $_{P}$H of about 5.65 (KARI, 2000).

2.2 PLANT MATERIALS

The genotypes evaluated comprised of 16 segregating rice populations (Table 1), developed at Mwea Research Station during the long rain season between March and June 2014 using a 6 x 6 half diallel mating design without reciprocals (Griffing, 1956). The objective of these crosses was to generate F_2 populations segregating for grain yield, resistance to rice blast, grain quality and drought tolerance. The parents were planted in buckets at the hybridization nursery in Mwea Research Station to produce the F_1 seeds that were subsequently selfed to produce 30 F_2 populations during the short rain season between September and December 2016.

The seven outstanding F_2 populations were selected using pedigree breeding method and evaluated at Mwea Research Station and Kirogo Experimental Farm during the cropping season of 2017 to generate the $F_{2:3}$ rice families. At maturity, the rice were harvested and dried to 14 % moisture content, processed and subjected to physico-chemical and culinary quality analysis.

Table 1. Characteristics of the rice germplasm used in the study

Germplasm	Characteristics
Basmati 370 (check)	Strong aroma, good grain quality and high adaptability to local conditions
WAB-56-104 (check)	High yield (7.5 t ha^{-1}), mild aroma and blast tolerant
MWUR 4 (check)	High yield (6 t ha^{-1}), high adaptability to local conditions
MWUR 4 x NERICA 4	MWUR 4 - high yield (6 t ha^{-1}); NERICA 4 - blast tolerance and long grains
NERICA 10 x KUCHUM	NERICA 10 - long grains, blast tolerance; KUCHUM - blast tolerance, earliness
NERICA 13 x K45	NERICA 13 - long grains, tolerance to leaf blast; K45 - high yielding (7.6 t ha^{-1}), earliness and well adapted to irrigated lowlands upland areas
NERICA 4 x MWUR 4	NERICA 4 - blast tolerance and long grains; MWUR 4 - high grain yield (6 t ha^{-1})
NERICA 4 x NERICA 1	NERICA 4 - blast tolerance, long grains; NERICA 1 - earliness, aroma
CG 14 x NERICA 10	CG 14 - earliness, mild aroma; NERICA 10 - long grains, blast tolerance
WAB-56-104 x NERICA 4	WAB-56-104 - high grain yield (8 t ha^{-1}), good grain quality; NERICA 4 - blast tolerance, long grains

2.3 DETERMINATION OF AGRONOMIC AND YIELD TRAITS

The agronomic traits were collected according to the procedure outlined in Standard Evaluation System (SES) for rice (IRRI, 2013). Data was collected on days to 50 % flowering, days to maturity, plant height, number of tillers $plant^{-1}$, number of effective tillers $plant^{-1}$, flag leaf length, panicle length, number of spikelet's $plant^{-1}$, number of fertile grains $panicle^{-1}$, grain yield and 1000 grain weight on individual plot basis.

2.4 DETERMINATION OF PHYSICAL GRAIN QUALITY

The physical properties of grain quality evaluated were grain length and grain shape. Grain length of 10 milled rice kernels for each genotype was measured using a vernier calliper (Model 530-312, Mitutoyo, Japan). Average length and width of the kernels were calculated (Suganthi and Nacchair, 2015). The length of the rice kernels were classified as very long (more than 7.5 mm), long (6.61 to 7.5 mm), intermediate (5.51 to 6.6 mm) and short (≤ 5.5 mm) (Dela Cruz and Khush, 2000). Grain shape was determined by dividing the mean length of each kernel by its corresponding breadth. Grain shape of the rice kernels were categorized as slender (over 3.0), medium (2.1 to 3.0), bold (1.1 to 2.0) and round (≤ 1.0) (Dela Cruz and Khush, 2000).

2.5 DETERMINATION OF CHEMICAL GRAIN QUALITY

The chemical grain quality properties evaluated were alkali spreading value, gelatinization temperature, gel consistency, aroma and cooking time. Alkali spreading value was determined using the procedure described by Little *et al.*, (1958). Gelatinization temperature of the rice kernels was determined by relating the kernel spreading values with the corresponding temperature range, the temperature normally vary between 50ºC to 79ºC and classified as low (55 to 69°C), intermediate (70 to 74°C) and high 75 to 79°C (Dela Cruz and Khush, 2000).

Gel consistency was determined according to the procedure described by Cagampang *et al.*, (1973). Gel consistency of the rice kernels were classified as follows: soft gel (61 to 100 mm), medium (41 to 60 mm) and hard gel (26 to 40 mm) (Dela Cruz and Khush, 2000).

Aroma was determined by weighing 2 g of milled rice kernels from each genotype and soaking it in 10 ml 1.7 % KOH solution at room temperature in a covered glass petri-plate for about 1 hour. The soaked rice kernels were rated on a scale of 1 to 4 by a test panel as follows: 1- no aroma; 2- slight aroma; 3- moderate aroma; and 4- strong aroma (Krishnan and Bhonsle, 2010).

Cooking time was determined by weighing 5 g of milled rice from each genotype and pouring it into 135 ml of boiling distilled water in a 400 ml beaker. After every ten minutes, 5 to 10 kernels were randomly taken out with a ladle and pressed between two petri dishes. The grains were considered cooked when they no longer have opaque centres and the time was recorded. The cooking time was determined using the formula: Cooking time = Final time - Initial time (Oko *et al.*, 2012).

2.6 DATA ANALYSIS

The data for agronomic traits and grain quality was subjected to analysis of variance according to Gomez and Gomez (1984) using GENSTAT 15th edition.

Descriptive statistic was used for grain dimension. Their means were separated using the least significant differences (LSD) at P≤0.05. The interrelationships among grain quality traits were computed according to Pearson (1986) using the statistical model: $P_{xy}= \frac{\sigma xy}{\sigma x \sigma y}$…………..Equation 1

Where: $\sigma_x\sigma_y$= population standard deviations and σ_{xy}= population variance.

3. RESULTS

3.1 ANALYSIS OF VARIANCE

The analysis of variance revealed significant differences (P≤0.05) among the $F_{2.3}$ families for all the agronomic characters studied at both Mwea Research Station and Kirogo Experimental Farm. There were significant differences (P≤0.05) among all the agronomic traits across sites except for number of spikelets panicle^{-1}. There was significant variation for genotype x site interaction for all the agronomic characters studied except for panicle length (Table 2).

Table 2. Analysis of variance for agronomic and yield traits among $F_{2.3}$ families grown for two seasons at Mwea Research Station and Kirogo Experimental Farm

		Sum of square										
Source of variation	d.f	50% Days to flowering	Days to maturity	Plant height (cm)	Number of tillers plant^{-1}	Flag leaf length (cm)	Panicle length (cm)	Number of panicles plant^{-1}	Number of spikelets panicle^{-1}	Number of filled grains panicle^{-1}	Grain yield (t ha^{-1})	1000 grain weight (g)
Replication	2	0.29	0.5	0.29	0.74	0.5	0.67	0.17	0.17	11.81	2.85	0.19
Genotype	6	162.71**	224.41**	22.30**	66.94**	35.99**	1.61*	143.10**	4.32**	631.10**	433.16**	1.55*
Site	1	13.71*	18.67*	981.17**	342.86**	594.38**	50.38**	1281.52**	1.93	28184.4**	5222.2**	6.52**
Genotype x Site	6	27.33**	17.00**	47.22**	33.08**	15.33**	0.659	28.08**	6.21**	980.27**	174.9**	5.10**
Residual	26	1.54	2.35	1.88	1.12	1.42	0.31	1.27	0.5	1.91	2.65	0.47

D.f= degrees of freedom, * Significance at 5 % level of probability, ** Significance at 1 % level of probability

3.2 AGRONOMIC PERFORMANCE OF $F_{2.3}$ FAMILIES ACROSS SITES

3.2.1 DAYS TO 50 % FLOWERING

All the genotypes tested differed significantly in reaching 50 % flowering in the two growing seasons across environments (Table 3). Days to 50 % flowering varied between 89.67 to 104.92 days. The genotypes WAB-56-104 x NERICA 4 (89.67 days), NERICA 4 x NERICA 1 (90.08 days), NERICA 10 x KUCHUM (90.67 days) and NERICA 4 x MWUR 4 (91.58 days) flowered early while NERICA 13 x K 45 (104.92 days) took longer day to 50 % flowering across environments. Compared to the checks WAB-56-104 consistently flowered earlier than the rest of the genotypes across the experimental sites.

3.2.2 DAYS TO MATURITY

There was significant variation ($P \leq 0.05$) in days to maturity among the tested genotypes in all environments (Table 3). Days to maturity ranged from 120.83 to 139.58 days. The genotypes NERICA 10 x KUCHUM (120.83 days), WAB-56-104 x NERICA 4 (121.58 days) were early maturing while NERICA 13 x K 45 (139.58 days) was late maturing across environments. The check Basmati 370 took the longest duration to maturity compared to all the genotypes tested at the two locations.

3.2.3 PLANT HEIGHT

The results showed that plant height exhibited significant differences ($P \leq 0.05$) among the tested genotypes at the two locations (Table 3). Plant height among the genotypes varied between 89.83 to 100.75 cm with NERICA 13 x K 45 (100.75 cm) exhibiting the tallest plants while CG 14 x NERICA 10 (89.83 cm), NERICA 4 x MWUR 4 (93.42 cm), NERICA 10 x KUCHUM (93.50 cm) and WAB-56-104 x NERICA 4 (94.92 cm) had short to intermediate plant height. The check parent Basmati 370 (129.17 cm) was the tallest genotype across environments.

3.2.4 NUMBER OF TILLERS PLANT^{-1}

The results showed that the number of tillers plant^{-1} displayed significant differences ($P \leq 0.05$) among the genotypes for the test environments (Table 3). The tiller number varied from 21.50 to 29.33 with CG 14 x NERICA 10 (29.33), WAB-56-104 x NERICA 4 (28.33) exhibited the highest tillers while NERICA 4 x

NERICA 1 (21.50) had the minimum number of tillers. Compared to the $F_{2.3}$ families tested, parent Basmati 370 exhibited the highest number of tillers (39.92) across environments.

3.2.5 FLAG LEAF LENGTH

The analysis of flag leaf length showed significant differences ($P \leq 0.05$) among the $F_{2.3}$ families tested (Table 3). Flag leaf length varied between 27.25 to 30.25 cm with NERICA 13 x K 45 (30.25 cm), NERICA 10 x KUCHUM (28.75 cm) and WAB-56-104 x NERICA 4 (28.42 cm) exhibiting the longest flag leaf while MWUR 4 x NERICA 4 (27.25 cm) had the least flag leaf length. The parent MWUR 4 (24.33 cm) had the least flag leaf length compared to the rest of genotypes evaluated.

3.2.6 PANICLE LENGTH

The genotypes differed significantly ($P \leq 0.05$) in panicle length across environments (Table 3). Panicle length varied from 21.0 to 21.67 cm with NERICA 10 x KUCHUM (21.67 cm) exhibiting the longest panicle while NERICA 4 x NERICA 1 (21.0 cm) had the shortest length of panicle. Compared to the $F_{2.3}$ families, the parent Basmati 370 (29.00 cm) had the longest panicle.

3.2.7 NUMBER OF EFFECTIVE TILLERS

The number of productive tillers plant^{-1} had significant differences ($P \leq 0.05$) among the genotypes across the tested environments (Table 3). Effective tillers per plant varied from 18.83 to 27.83 with WAB-56-104 x NERICA 4 (27.83) exhibiting the highest number of effective tillers while MWUR 4 x NERICA 4 (18.83) had the minimum number of effective tillers across environments. Compared to the $F_{2.3}$ families tested, the Basmati 370 (34.17) had the highest number of effective tillers per plant.

3.2.8 NUMBER OF FERTILE GRAINS PANICLE^{-1}

The results revealed significant variation ($P \leq 0.05$) for number of tillers among the tested genotypes across locations (Table 3). The fertile grains per panicle varied from 107.5 to 129.92 with MWUR 4 x NERICA 4 (129.92), WAB-56-104 x NERICA 4 (128.75) exhibiting the highest number of fertile grains per panicle while NERICA 13 x K 45 (107.5) had the minimum fertile grains per panicle. The check NERICA 10 (100.33) exhibited the least number of fertile grains per panicle among the tested genotypes.

3.2.9 GRAIN YIELD

Grain yield differed significantly ($P \leq 0.05$) among the genotypes tested in all environments (Table 3). Grain yield varied from 4.08 to 9.35 t ha^{-1}. Highest grain yield was observed in WAB-56-104 x NERICA 4 (9.35 t ha^{-1}) while NERICA 13 x K 45 (4.08 t ha^{-1}) was the lowest grain yielder. Compared to the $F_{2.3}$ families evaluated, the check KUCHUM (3.94 t ha^{-1}) was the lowest grain yielder.

3.2.10 1000-GRAIN WEIGHT

Significant differences ($P \leq 0.05$) among the tested genotypes were observed for 1000-grain weight in all environments (Table 3). 1000-grain weight varied from 22.92 to 24.99 g with WAB-56-104 x NERICA 4 (24.99

g) exhibiting the heaviest 1000 grain weight while NERICA 13 x K 45 (22.92 g) had the lightest 1000-grain weight.

Table 3. Agronomic performance of $F_{2.3}$ families at Mwea Research Station and Kirogo Experimental Farm

				Agronomic traits					Yield traits		
Genotype	**Days to 50% flowering**	**Days to maturity**	**Plant height (cm)**	**Number of tillers plant^{-1}**	**Flag leaf length (cm)**	**Panicle length (cm)**	**Number of panicles plant^{-1}**	**Number of spikelets panicle^{-1}**	**Number of filled grains panicle^{-1}**	**Grain yield (t ha^{-1})**	**1000 grain weight (g)**
Basmati 370 (check)	106.21	139.50	129.17	39.92	44.50	29.00	34.17	11.33	110.67	3.43	24.83
NERICA 4 (check)	87.33	131.17	92.33	23.33	26.67	21.83	22.50	12.33	111.50	4.80	22.60
KUCHUM (check)	92.17	129.42	93.58	22.67	27.83	20.92	19.67	12.25	115.67	3.94	22.67
MWUR 4 (check)	87.17	128.33	93.67	19.83	24.33	21.17	18.00	11.00	115.50	5.72	22.62
WAB-56-104 (check)	88.42	124.75	99.58	22.42	28.67	21.17	20.50	11.75	125.33	6.56	23.12
NERICA 1 (check)	83.83	119.17	87.83	24.00	26.50	21.50	22.00	10.03	105.17	5.35	24.56
NERICA 10 (check)	82.00	121.83	83.50	16.17	26.33	21.50	15.00	11.00	100.33	4.01	20.54
NERICA10 x KUCHUM	90.67	120.83	93.50	22.58	28.75	21.67	21.17	11.50	116.08	5.85	23.60
NERICA13 x K45	104.9	139.58	100.75	22.83	30.25	21.17	20.25	10.42	107.50	4.08	22.92
MWUR4 x NERICA4	95.17	130.00	95.33	21.67	27.25	21.50	18.83	11.83	129.92	5.02	24.39
NERICA4 x MWUR4	91.58	126.25	93.42	22.42	28.50	21.33	21.75	11.08	119.83	6.05	23.51
NERICA4 x NERICA1	90.08	123.33	95.83	21.50	27.33	21.00	21.08	11.75	118.17	6.76	23.71
CG14 x NERICA10	94.08	135.08	89.83	29.33	29.58	21.25	24.50	11.08	122.83	4.73	23.64
WAB-56-104 x NERICA4	89.67	121.58	94.92	28.33	28.42	21.17	27.83	12.17	128.75	9.35	24.99
Grand mean	**90.81**	**126.07**	**93.39**	**22.65**	**28.04**	**21.32**	**21.31**	**11.71**	**119.05**	**5.69**	**23.47**
LSD 5 %	**3.7**	**2.93**	**3.03**	**2.68**	**1.83**	**0.93**	**2.53**	**1.21**	**12.13**	**0.65**	**1.15**
CV %	**3.6**	**2.0**	**2.8**	**10.4**	**5.7**	**3.8**	**10.4**	**9.0**	**8.9**	**9.9**	**4.3**

L.S.D= Least significant differences of means at ($p \leq 0.05$), C.V%= Coefficient of variation

3.3 PHYSICAL GRAIN QUALITY

The results for physical grain quality are presented in Table 4. There were significant differences ($P \leq 0.05$) among the $F_{2.3}$ families for grain length. Grain length of the $F_{2.3}$ families varied from 6.84 to 7.06 mm with a mean value of 6.93 mm. Maximum grain length was recorded in MWUR 4 x NERICA 4 while NERICA 4 x MWUR 4 had the least grain length. The check variety Basmati 370 had a very long grain length compared to all the $F_{2.3}$ families evaluated. Grain width was not significantly different ($P \leq 0.05$) among the genotypes tested. Grain width of the $F_{2.3}$ families varied from 2.10 to 2.68 mm with a mean value of 2.43 mm. The $F_{2.3}$ families of MWUR 4 x NERICA 4 and NERICA 13 x K45 exhibited high grain width while NERICA 4 x MWUR 4 had the lowest grain width. There were significant differences ($P \leq 0.05$) for length to width ratio among the $F_{2.3}$ families. Length to width ratio varied from 2.54 to 3.19 with a mean value of 2.94. The $F_{2.3}$ families of NERICA 4 x MWUR 4, NERICA 10 x KUCHUM and NERICA 4 x NERICA 1 exhibited high length to width ratio while NERICA 13 x K45 had the lowest. The check variety Basmati 370 had the highest length to width ratio among the tested genotypes.

3.4 CHEMICAL GRAIN QUALITY

The results for chemical grain quality are presented in Table 5. There were significant differences (P≤0.05) for cooking time among the rice genotypes. The $F_{2.3}$ families of NERICA 13 x K45, NERICA 10 x KUCHUM took longer time to cook while NERICA 4 x NERICA 1 and MWUR 4 x NERICA 4 cooked fast. The sensory test showed that the $F_{2.3}$ families of MWUR 4 x NERICA 4, NERICA 4 x MWUR 4, CG 14 x NERICA 10 and WAB-56-104 x NERICA 4 were slightly aromatic while NERICA 10 x KUCHUM, NERICA 13 x K45 and NERICA 4 x NERICA 1 were non-aromatic. The check Basmati 370 had strong aroma compared to all the $F_{2.3}$ families evaluated. The alkali digestion of the rice kernels varied from 2-7 among the genotypes indicating a wide range of gelatinization temperature. The $F_{2.3}$ families of NERICA 4 x NERICA 1, MWUR 4 x NERICA 4 had alkali digestion scale 6 while WAB-56-104 x NERICA 4 had scale 7 but NERICA 10 x KUCHUM exhibited scale 4. The $F_{2.3}$ families of NERICA 4 x MWUR 4 showed scale 2 while NERICA 13 x K45 and CG 14 x NERICA 10 had scale 3. Gelatinization temperature was significantly different (P≤0.05) among the rice genotypes. The $F_{2.3}$ families of NERICA 13 x K45 had the highest gelatinization temperatures while NERICA 4 x NERICA 1 and MWUR 4 x NERICA 4 had the lowest. There was marked variation in gel length among the genotypes tested. It varied from 45 to 65 mm. The $F_{2.3}$ families of WAB-56-104 x NERICA 4, NERICA 4 x NERICA 1 and MWUR 4 x NERICA 4 exhibited the highest gel consistency while NERICA 13 x K45 had low gel consistency.

3.5 CORRELATIONS BETWEEN PHYSICO-CHEMICAL CHARACTERS

There were significant (P≤0.05) correlations among the physico-chemical characters (Table 6). Rice genotypes that exhibited longer cooking time (r = 0.58**) had low gel consistency but those with low alkali digestion value had high gelatinization temperature and took longer cooking time (r = 0.35**). The $F_{2.3}$ families with long grains had shorter cooking time (r = -0.69**) and low gel consistency (r = -0.61**) but higher length to width ratio (r = 0.55*) while rice genotypes with high grain length had high grain width (r = 0.509*) but lower length to width ratio (r = -0.383*) and gel consistency (r = -0.698**).

Table 4. Physical grain quality of $F_{2.3}$ families grown at Mwea Research Station during 2016 and 2017 cropping season

Genotype	Grain length (mm)	Grain width (mm)	Length to width ratio	Grain shape category	Grain length category
Basmati 370 (check)	7.86	2.67	3.32	Slender	Very long
WAB-56-104 (check)	6.82	2.45	2.78	Medium	Long
MWUR 4 (check)	6.75	2.40	2.81	Medium	Long
MWUR 4 x NERICA 4	7.06	2.68	2.94	Medium	Long
NERICA 10 x KUCHUM	6.92	2.20	3.15	Slender	Long
NERICA13 x K45	6.72	2.65	2.54	Medium	Long
NERICA 4 x MWUR 4	6.69	2.10	3.19	Slender	Long
NERICA 4 x NERICA 1	6.75	2.20	3.07	Slender	Long
CG 14 x NERICA 10	6.89	2.45	2.81	Medium	Long
WAB-56-104 x NERICA 4	6.84	2.50	2.74	Medium	Long
Grand Mean	6.93	2.43	2.94	-	-
CV %	2.1	0.10	0.13	-	-
LSD 5 %	0.42	0.23	0.56	-	-

LSD = Least significant differences of means at (P≤0.05), CV = Coefficient of variation

Table 5. Chemical grain quality of $F_{2.3}$ families grown at Mwea Research Station during 2016 and 2017 cropping season

Genotype	Aroma test	Cooking time (min)	Alkali spreading value	Gelatinization Temperature (^{0}C)	Temperature category	Gel Consistency (mm)	Gel category
Basmati 370 (check)	Strong	23.67	4	70.00	Intermediate	40	Hard gel
WAB-56-104 (check)	No	24.67	6	65.00	Low	65	Soft gel
MWUR 4 (check)	No	25.33	6	55.00	Low	64	Soft gel
MWUR 4 x NERICA 4	Slight	23.33	6	58.67	Low	63	Soft gel
NERICA 10 x KUCHUM	No	43.33	2	75.00	High	53	Medium
NERICA 13 x K45	No	45.33	3	79.00	High	45	Medium
NERICA 4 x MWUR 4	Slight	37.33	2	76.00	High	48	Medium
NERICA 4 x NERICA 1	No	22.33	6	57.00	Low	63	Soft gel
CG 14 x NERICA 10	Slight	40.67	3	78.00	High	60	Medium
WAB-56-104 x NERICA 4	Slight	22.67	7	69.00	Low	65	Soft gel
Grand Mean	-	39.47	4.3	67.87	-	60.6	-
CV %	-	0.94	0	0.10	-	0	-
LSD 5 %	-	1.9	0	0.31	-	0	-

LSD = Least significant differences of means at ($P \leq 0.05$), CV = Coefficient of variation

Table 6. Correlations between physico-chemical characters

	Alkali spreading value	Length to width ratio	Cooking time (min)	Gel consistency (mm)	Gelatinization temperature (^{0}C)	Grain length (mm)
Length to width ratio	-0.059	-				
Cooking time (min)	0.13	-0.339	-			
Gel consistency (mm)	0.132	0.055	0.582**	-		
Gelatinization temperature (^{0}C)	-0.674**	-0.072	0.355**	-0.269	-	
Grain length (mm)	0.039	0.554*	-0.691**	-0.611**	0.023	-
Grain width (mm)	0.166	-0.383*	-0.348	-0.698**	0.004	0.509*

Significant correlation at 5 % level of probability, ** Significant correlation at 1 % level of probability

4. DISCUSSION

The evaluation of $F_{2.3}$ families for yield potential and grain quality revealed high genetic variation among the rice genotypes. The $F_{2.3}$ families used in the study were from diverse genetic sources, some of the genotypes were locally improved at Industrial Crops Research Center in Mwea while others were introductions generated from interspecific hybridization between cultivated rice species of *Oryza sativa* and *Oryza glabberima*. This explains the genetic variability among the tested $F_{2.3}$ families. Ovung et al., (2012) reported that the presence of large genetic variability among rice genotypes could be due to diverse sources of germplasm as well as the influence of the growth environment. Similar genetic variations among diverse genotypes were also reported by (Akinwale et al., (2011) and Rashid et al., (2013) who observed significant genotypic variations among rice genotypes for all the agronomic and yield traits studied.

Evaluation of the $F_{2.3}$ families for agronomic and yield traits revealed that WAB-56-104 x NERICA 4 and NERICA 10 x KUCHUM and NERICA 4 x NERICA 1 had short duration to maturity. Therefore, these short genotypes can be used by breeders to develop early maturing genotypes. The results further revealed that the $F_{2.3}$ families of WAB-56-104 x NERICA 4 and NERICA 10 x KUCHUM and NERICA 4 x NERICA 1 had relatively short to intermediate height and exhibited higher grain yields across sites. The higher number of productive tillers exhibited by these genotypes was due to higher sink to source ratio, spikelet number, proportion of filled grains, and leaf area per panicle and sink capacity (Choi and Kwon, 1985). The high yielding $F_{2.3}$ families could be selected for further grain yield improvement because they consistently maintained higher grain yields in all locations suggesting a wider adaptability to varying environments. In order to improve grain yield of rice genotypes, plant breeders need to focus on developing rice plants bearing more number of panicles with high tillering ability, this could lead to tremendous increase in gain yield. Grain yield is determined by several agronomic traits such as days to heading, days to maturity, grain filling period, number of effective tillers, number of filled grains per panicle, panicle length and plant height (Halil and Necmi, 2005).

The physical grain quality showed that the $F_{2.3}$ families of NERICA 4 x MWUR 4, NERICA 10 x KUCHUM and NERICA 4 x NERICA 1 had higher length to width ratio suggesting slender grain shape, in contrast NERICA 13 x K45, WAB-56-104 x NERICA 4, CG 14 x NERICA 10 and MWUR 4 x NERICA 4 exhibited a length to width ratio of between 2.1 and 3.0 suggesting a medium grain shape. Slender grain shape was also reported in upland rice varieties (Shejul *et al.*, 2013 and Chukwuemeka *et al.*, 2015). Previous studies reported medium grain shape category in local rice varieties (Singh *et al.*, 2012 and Basri *et al.*, 2015). However, the check variety Basmati 370 had slender grain shape with relatively higher length to width ratio than the non-Basmati rice genotypes. Similar findings were reported by Bhonsle and Sellappan (2010) and Yadav *et al.*, (2016) who studied physico-chemical and cooking properties of some Indian rice varieties of Basmati and non-Basmati. Compared to all the $F_{2.3}$ families evaluated, the check variety Basmati 370 had the highest grain length. Similar findings were observed by Yadav *et al.*, (2007) who reported a significantly higher grain length in Indian Basmati rice than non-Basmati varieties. Rice grain quality depends on physico-chemical properties which are greatly influenced by the genotype of the plant (Kishine *et al.*, 2008). Determining the physical qualities of rice cultivars is very important because the physical appearance of milled rice is important to the consumer, miller and the marketer (Fofana *et al.*, 2011). Rice breeders consider grain shape and grain size as the most important rice quality parameters when developing new rice varieties for commercial production because consumer preference for grain shape and size vary from one group of consumers to another (Sellappan *et al.*, 2009). Length to width ratio is important in classification of grain shape. A higher value of over 3 indicate a slender shape, a value between 2.1 and 3.0 reveals a medium shape and a lower value indicate a bold or round shape (Rita and Sarawgi, 2008). Long and slender rice grains are mostly preferred by many consumers and such grains normally fetch higher prices at the international market (Singh *et al.*, 2010). Therefore, the physical grain qualities exhibited by NERICA 4 x MWUR 4, NERICA 10 x KUCHUM and NERICA 4 x NERICA 1 can be exploited in a breeding program designed to improve the grain length and shape of local rice cultivars.

The chemical grain quality showed that the $F_{2.3}$ families of CG 14 x NERICA 10, NERICA 4 x MWUR 4, NERICA 13 x K45 and NERICA 10 x KUCHUM had high gelatinization temperatures implying that the starch granules in these genotypes took longer time to start the process of cooking while WAB-56-104 x NERICA 4, NERICA 4 x NERICA 1 and MWUR 4 x NERICA 4 had low gelatinization temperature and cooked fast. Similar findings were also reported (Oko *et al.*, 2012; Parikh *et al.*, 2012). The check variety Basmati 370 had intermediate gelatinization temperature and showed partial disintegration in dilute alkali solution. Similar findings were reported in check rice varieties by Hossain *et al.*, (2009). Low alkali digestion values and high gelatinization temperature were reported in rice germplasm (Singh *et al.*, 2012). The variation in gelatinization temperature among the rice genotypes could be attributed to higher ambient temperature during grain ripening period that led to formation of starch with high gelatinization temperature (Singh *et al.*, 2010). The $F_{2.3}$ families of WAB-56-104 x NERICA 4, NERICA 4 x NERICA 1 and MWUR 4 x NERICA 4 had high gel consistency while NERICA 13 x K45 had low gel consistency. These results are in agreement with the findings of Oko *et al.*, (2012), Shejul *et al.*, (2013) and Tamu (2015).The variation in the gel consistency indicated that $F_{2.3}$ families with soft gel cooked more tenderly and remained soft even upon cooking while those with hard gel harden faster upon cooling than those with medium and soft gel. In terms of aroma, the $F_{2.3}$ families of MWUR 4 x NERICA 4, NERICA 4 x MWUR 4, CG 14 x NERICA 10 and WAB-56-104 x NERICA 4 had mild aroma while NERICA 10 x KUCHUM, NERICA 13 x K45 and NERICA 4 x NERICA 1 were non-aromatic. Similar results were reported (Seraj *et al.*, 2013). Aromatic rice varieties command premium prices at the international market (Dela Cruz and Khush, 2000). Sensory analysis helps the consumer to select better rice variety for consumption (Singh *et al.*, 2012). Therefore, the results of the sensory test revealed the need for further improvement of this trait (aroma) in the $F_{2.3}$ families evaluated.

4.1 CORRELATION BETWEEN GRAIN QUALITY TRAITS

Cooking time was strongly correlated with gelatinization temperature and gel consistency implying that rice genotypes with high gelatinization temperature required more cooking time but those with low gelatinization temperature took short time to cook and had soft texture. Similar findings were also reported (Oko *et al.*, 2012 and Yadav *et al.*, 2016). Cooking time was negatively correlated with grain length suggesting that an increase in grain length result in reduction in cooking time. Alkali spreading value was negatively correlated with gelatinization temperature suggesting that gelatinization temperature decreases with increase in alkali digestion value. Similar results were also reported (Singh *et al.*, 2012 and Basri *et al.*, 2015). Low value of alkali digestion indicates that the rice kernels are largely unaffected in dilute alkali solution and therefore require high temperature to cook. This is contrary to the findings of Tamu (2015) who reported a strong and significant correlation of alkali spreading value with gelatinization temperature. Grain length was strongly correlated with grain width implying that an increase in grain length results in a significant increase in grain width. This is contrary to the findings of Seraj *et al.,* (2013) who reported significant and negative correlation of grain length with grain width. Gel consistency was negatively correlated with grain length and grain width implying that rice genotypes with long grain and high grain width have low gel consistency. Correlation analysis is an important tool that helps plant breeders to indirectly select for a farmer preferred trait (Seraj *et al.*, 2013). Therefore, correlation studies for the physico-chemical traits suggested that efforts aimed at selecting rice varieties with improved cooking quality traits requires a consideration of the physico-chemical qualities of the rice grain (Oko *et al.*, 2012).

5. CONCLUSIONS

Evaluation of the $F_{2.3}$ families for yield potential, earliness and grain quality showed that the three families namely WAB-56-104 x NERICA 4, MWUR 4 x NERICA 4 and NERICA 4 x NERICA 1 out of 16 populations studied were early maturing, exhibited short to intermediate plant height and consistently maintained higher grain yields across sites suggesting a wider adaptability to varying environments. In addition these three rice families exhibited better culinary and physico-chemical qualities. However, the check variety Basmati 370 was outstanding for physical grain quality and aroma compared to the non-Basmati rice genotypes suggesting that Basmati 370 has implication for future breeding.

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6. REFERENCES

Akinwale, G. M., Gregorio, G., Nwile, F., Akinyele, B. O., Agunbayo, 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 Sciences*, 5(3), 207-212.

Basri, F., Sharma, H. P., Jain, P., and Mahto, G. (2015). Grain quality and starch evaluation of local varieties of rice growing in Jharkhand State, India. *International Journal of Current Research*, 7(1), 11895-11900.

Bhonsle, S. J., and Krishnan, S. (2010). Grain quality evaluation and organoleptic analysis of aromatic rice varieties of Goa, India. *Journal of Agricultural Science*, 2(3), 99-107.

Bhonsle, S. J., Sellappan, K. (2010). Grain quality evaluation of traditionally cultivated rice varieties of Goa, India. *Recent Research in Science and Technology*, 2, 88-97.

Cagampang, G. B., Perez, C. M., and Juliano, B. O. (1973). A gel consistency test for eating quality of rice. *Journal of Food Science Agriculture*, 24(1), 1589-1594.

Choi, H. C., and Kwon, K. W. (1985). Evaluation of varietal difference and environment variation for some characters related to source and sink in the rice plants. *Korean Journal of Crop Science*, 30, 460 470.

Chukwuemeka, I. A., Kelechi, A. J., and Bernard, A. (2015). Cooking and physico-chemical properties of five rice varieties produced in Ohaukwu local government area. *European Journal of Food Science and Technology*, 3(1), 1-10.

Dela Cruz, N., G. S. Khush. (2000). Rice grain quality evaluation procedures: Aromatic rice. (R.K. Singh, U.S, Eds.). New Delhi: Oxford and IBH Publishing Co. Pvt. Ltd.

Dela Cruz, N., Kumar, I., Kaushik, R. P., and Khush, G. S. (2002). Effect of temperature during grain development on stability of cooking quality components in rice. *Japan Journal of Breeding*, 39(10), 299-306.

Fofana, M., Futakuchi, K., Manful, J. T., Yaou, I. B., Dossou, J., and Bleoussi, R. T. M. (2011). Rice grain quality: A comparison of imported and local rice varieties with new varieties adopted in Benin. *Journal of Food Control*, 22(12), 1821-1825.

Food and Agriculture Organization Statistics (FAOSTAT). (2017). Paddy rice production database. Bangkok. http://www.faostat3.fao.org

Gomez, A. K., and Gomez, A. A. (1984). Statistical Procedure for Agricultural Research. Manila, Philippines: John Wiley and Sons, Inc.

Griffing, B. (1956). Concept of general and specific combining ability in relation to diallel crossing system. *Australian Journal of Biological Sciences*, 9(4), 463-493.

Halil, S., and Necmi, B. (2005). Selection for grain yield and its components in early generations in rice (Oryza sativa L.). *Trakya University Journal of Science*, 6(1), 51-58.

Hossain, S., Singh, A. K., and Zaman, F. (2009). Cooking and eating qualities of some newly identified inter sub-specific (indica/japonica) rice hybrids. *ScienceAsia*, 35, 320-325.

International Rice Research Institute (IRRI). (2013). Standard Evaluation System (SES) for Rice (5thed.). Los Banos, Philippines.

Juliano, B. O. (1993). Rice in Human Nutrition (26th ed.). Rome. http://books.irri.org/9251031495_content.pdf

Kenya Agricultural and Livestock Research Organization (KALRO). (2014). The Kenyan rice knowledge bank (Kore, W., Kimani, J., Okiyo, T., Onyango, G and Okora, J. Eds). http://www.kalro.org/ricebank/index.php/home/rice-regions/41-rice-regions/varietie

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

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.

Kishine, M., Suzuki, K., Nakamura, S., and Ohtsubo, K. (2008). Grain qualities and their genetic derivation of seven NERICA varieties. *Journal of Agriculture and Food Chemistry*, 56(1), 4605-4610.

Kohnaki, M. E., Kiani, G., and Nematzadeh, G. (2013). Relationship between morphological traits in rice restorer lines at F3 generation using multivariate analysis. *International Journal of Advance Biology and Biomedical Research*, 1(6), 572-577.

Little, R. R., Hilder, G. B., and Dawson, E. H. (1958). Differential effect of dilute alkali on 25 varieties of milled white rice. *Journal of Cereal Chemistry*, 35(1), 111-126.

Ministry of Agriculture (MoA). (2014). National rice development strategy 2008-2018: Agriculture Information Center, Nairobi-Kenya.

Ngotho, A. (2017). Farewell to irrigation: Scientists develop prolific, rainfed rice variety. 'The STAR June, 2018, upcountry edition'.

Oko, A. O., Ubi, B. E., and Dambaba, N. (2012). Rice cooking quality and physico-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.

Ovung, C.Y., Lal, G. M., & Prashant, K. R. (2012). Studies on genetic diversity in rice (Oryza sativa L.). *Journal of Agricultural Technology*, 8(3), 1059-1065.

Parikh, M., Rastogi, N. K., and Sarawgi, A. K. (2012). Variability in grain quality traits of aromatic rice. *Bangladesh Journal of Agriculture Research*, 37(4), 551-558.

Pearson, K. (1986). Mathematical contributions to the theory of evolution: On a form of spurious correlation which may arise when indices are used in the measurement of organs. Proceedings of the Royal Society of London. 60, 489-498. London, UK.

Rashid, K., Khaliq, I., Farooq, M. O., and Ahsan, M. Z. (2013). Correlation and cluster analysis of some yield and yield related traits in rice (Oryza sativa L.). *International Journal of Agricultural Science and Research*, 3(4), 25-30.

Rita, B. and Sarawgi, A. K. (2008). Agro-morphological and quality characterization of badshah bhog group from aromatic rice germplasm of Chhattisgarh. *Bangladesh Journal of Agriculture Research*, 33, 479-492.

Sellappan, K., Datta, K., Parkhi, V. and Datta, S.K. (2009). Rice caryopsis structure in relation to distribution of micronutrients (iron, zinc, B-carotene) of rice cultivars including transgenic indica rice. *Plant Science*, 177, 557-562.

Seraj, S., Hassan, L., Begum, S. N., and Sarker, M. M. (2013). Physico-chemical attributes and correlation among grain quality traits of some exotic aromatic rice lines. *Journal for Bangladesh Agriculture University*, 11(2), 227-232.

Shejul, M. B., Deosarkar, D. B., Kalpande, H. V., Chavan, S. K., Deshmukh, V. D., Dey, U., and Arbad, S. K. (2013). Variability studies for grain quality characters in upland rice. *African Journal of Agricultural Research*, 8(38), 4872-4875.

Singh, A. K., Singh, P. K., Nandan, R., Rao, M. (2012). Grain quality and cooking properties of rice germplasm. *Annals of Plant and Soil Research*, 14, 52-57.

Singh, M. K., Pachauri, V., Singh, A. K., Singh, S., Shakeel, N. A., Singh, V. P., and Singh, N. K. (2010). Origin and genetic diversity of aromatic rice varieties: Molecular Breeding, Chemical and Genetic basis of Rice Aroma. *Journal of Plant Biochemistry and Biotechnology*, 19(2), 127-143.

Suganthi, A., and Nacchair, F. (2015). Quality parameters of different varieties of paddy rice grown in Vadakkanchery, Kerala. *International Journal of Advances in Pharmacy, Biology and Chemistry*, 4(2), 405-408.

Tamu, A. (2015). Grain quality characterization of 87 rice (Oryza sativa L.) accessions in Ghana. MSc. Agronomy, Kwame Nkrumah University of Science and Technology.

Yadav, R. B., Khatkar, B. S., and Yadav, B. S. (2007). Morphological, physico-chemical and cooking properties of some Indian rice (Oryza sativa L.) cultivars. *Journal of Agriculture Technology*, 3(1), 203-210.

Yadav, R. B., Malik, S., and Yadav, B. S. (2016). Physico-chemical, pasting, cooking and textural quality characteristics of some Basmati and non-Basmati rice varieties grown in India. *International Journal of Agricultural Technology*, 12(4), 675-692.