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**Kossi Lorimpo Adjah, Ayodeji Abe,
Victor O. Adetimirin & Maxwell Darko
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RESEARCH ARTICLE

Genetic variability, heritability and correlations for milling and grain appearance qualities in some accessions of rice (*Oryza sativa* L.)

Kossi Lorimpo Adjah^{1,2} · Ayodeji Abe¹ · Victor O. Adetimirin¹ · Maxwell Darko Asante²

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Abstract Poor milling and grain appearance is a common feature of locally produced rice (*Oryza sativa* L.) in West Africa. Development of genotypes with high yield and uniform milled grain size will enhance the market for the locally produced rice. One hundred rice accessions were evaluated to assess genetic variability, heritability and correlations for 11 milling and appearance quality traits and grain yield. The field was laid as a 10 × 10 alpha lattice design with three replications following standard cultivation practices. ANOVA revealed significant differences for the traits studied. The genotypic and environmental variances showed significant differences for all characters studied. Phenotypic coefficient of variation was greater than its corresponding genotypic coefficient of variation for each studied trait. Heritability at broad-sense varied from 14.1% for milling degree to 73.8% for milled grain length-to-width ratio (L/W). Genetic advance as percent of mean ranged from 2.2% for brown rice recovery to 129.6% for percentage of grain with chalkiness (PGWC). In general, genotypic correlations ranged higher than their corresponding phenotypic correlations. Brown rice recovery had significant positive phenotypic and genotypic correlations with milling recovery and head rice recovery. Consequently, brown rice recovery, milling recovery and L/W could be used as selection criteria for the improvement of head rice recovery. Genotypes BETIA and CRI-AMANKWATIA had the desirable PGWC and degree

of chalkiness, therefore, they are recommended for the improvement of high yielding varieties with high amount of chalkiness.

Keywords Genotypic and phenotypic coefficient of variation · Milled grain · Appearance quality · Heritability · Genetic advance

Introduction

The world population is predicted to reach nine billion by the year 2050 and food insecurity could become a serious global problem (Alexandratos and Bruinsma 2012). Therefore, it is crucial to augment the productivity of major cereal crops such as rice to satisfy the increasing demand of a population that keeps on growing (Fitzgerald et al. 2009). Rice is cultivated in rain-fed upland and aquatic ecologies in 40 countries in Africa on nearly 10 million hectares (Negussie et al. 2017). Although West Africa has about 4.4 million hectares planted to rice (Somado et al. 2008), there exist a production deficit due to increasing demand which surpasses local production. Many of the countries in West Africa therefore rely on imports to meet consumer demands. To bridge the gap created by the production shortage, rice breeding programmes in West Africa have concentrated essentially on yield improvement and adaptation to the difficult production environments leaving behind the improvement of grain quality (Manful 2010). Consequently, yield and tolerance to different stresses have been improved (Saito et al. 2012) but problems with the quality of locally produced rice persists. The poor quality of the locally produced rice available in the market is a combination of the types of rice varieties grown, mediocre

✉ Maxwell Darko Asante
mdasante@gmail.com

¹ Pan African University Life and Earth Sciences Institute (PAULESI) University of Ibadan, Ibadan, Nigeria

² Council for Scientific and Industrial Research – Crops Research Institute (CSRI-CRI), Fumesua-Kumasi, Ghana

postharvest management and processing methods (Futakuchi et al. 2013).

Rice grain quality encompasses the totality of all characteristics feature of rice or rice products that meet consumer demands and preferences (Siddiqui et al. 2007). Generally, the parameters used to assess grain quality in rice vary for different countries. However, four main quality characters are essentially used, namely milling characteristics, appearance quality, nutritional value and cooking quality (Yu et al. 2008; Asante 2017). Rice grain quality has become a foremost consideration for rice breeders and consumers. Grain appearance in terms of shape and chalkiness is a crucial factor affecting its market acceptability. Grain shape is described by the length, width and length-to-width ratio of the grain. Chalkiness in rice is usually assessed by the degree of endosperm chalkiness and the percentage of grain with chalkiness. The varieties with percentage of grain with chalkiness higher than 20% are less preferred in most world's markets (Chen et al. 2011). The presence of chalky areas in rice grains is generally a sign of lower quality of the grains and thus attracts lower market prices. The milling yield of the grain determines the yield of the head rice and the broken kernel rate of the milled rice (Yi and Mei 2012). Milling properties are usually evaluated by brown rice recovery, milled rice recovery and head rice recovery (Wang et al. 2017). Head rice is the whole unbroken rice grains obtained from milling. The broken grains essentially reduce the price of rice by 50% (Oyedele and Adeoti 2013).

To meet the consumer preference and market demands, improvement of grain quality is the most important objective next to yield enhancement (Sahu et al. 2017). Therefore, breeding rice varieties that encompass desirable milling and appearance quality becomes a prime objective for rice breeders around the world (Wang et al. 2017). Several workers such as Sahu et al. (2017), Parikh et al. (2012) and Fatema et al. (2011) have studied various genetic variability parameters and correlations on rice grain quality. However, to date, the genetic variability for milling and appearance quality of most rice germplasm in Africa has not been thoroughly studied. Breeders' require information on the genetic variability in their germplasm and heritability of target traits to predict gain from selection. Trait selection requires knowledge of nature and magnitude of genotypic variation, transmissibility and selection progress. The following parameters, namely genotypic coefficient of variation, phenotypic coefficient of variation, heritability and genetic advance are usually used to measure genetic variability (Hossain et al. 2015). In breeding for improved grain quality of rice, the knowledge of the correlations between grain yield and the milling quality traits is important for the identification of suitable selection criteria for effective yield and grain quality

improvement. This study aimed to quantify the genetic variability among 100 rice accessions for milling and appearance quality traits, determine the association among rice yield and milling quality traits, and identify suitable genotypes with desirable milling and appearance qualities. A good knowledge of available genetic materials will help breeders to identify suitable genotypes for hybridization.

Materials and methods

Genetic materials and planting

One hundred genotypes (Table 1) were used for this study. The study was conducted at the Crops Research Institute of Council of the Scientific and Industrial Research (CSIR-CRI) in Fumesua-Kumasi, Ghana during the major planting season of 2018. Twenty-day old seedlings were transplanted on 09 March 2018 into a lowland field laid as 10×10 alpha lattice design with three replications. Plot size was 1 m x 1 m with between and within row spacing of 20 cm each. The field was fertilized with N_2 , P_2O_5 , and K_2O at the ratio 90:60:60 kg ha⁻¹ through hand broadcasting. One-third of N and the full amounts of P and K were applied during final land preparation. The second and third increments of N were applied at the tiller stage and at panicle initiation, respectively. Manual weeding was done at two weeks after planting and prior to flowering.

Data collection

Milling and appearance quality traits

One hundred grams of paddy of each accession per replicate was milled at 14% moisture content using Zaccaria Testing Rice Mill (model PAZ/1-DTA). One hundred grams of the paddy rice was de-husked to obtain brown rice through the Paddy husker of the Rice Mill with the timer set at 15 s. Whitening of the brown rice was done by abrasive action, using the Whitener with the timer set at 60 s to obtain the white rice (milling yield). The separation of broken grains from the head rice was done through indented cylinder (5.5 mm) by selecting the grading mode with the timer set at 60 s. The weights of brown rice, white rice, head rice and broken rice were taken, and calculations were done based on the procedure of IRRI (IRRI 2010; Abacar et al. 2016):

Brown rice recovery (BRR)

$$= (\text{wt of brown rice (g)}/\text{wt of paddy(g)}) \times 100$$

Table 1 Background information of rice genotypes evaluated in the study

S/no.	Genotype	Source	S/no.	Genotype	Source	S/no	Genotype	Source
1	ART58-5-1-1-B-B	AfricaRice	35	ART98-147-1-2-B-B	AfricaRice	69	AGRA-CRI-LOL-1-21	CRI-Kumasi
2	ART58-46-1-1-B-B	AfricaRice	36	ART100-16-1-2-B-B	AfricaRice	70	CRI-1-11-15-5	CRI-Kumasi
3	ART58-51-1-2-B-B	AfricaRice	37	ART100-56-1-1-B-B	AfricaRice	71	AGRA-CRI-LOL-1-7	CRI-Kumasi
4	ART64-26-1-1-B-B	AfricaRice	38	ART100-57-1-2-B-B	AfricaRice	72	CRI-1-11-15-21	CRI-Kumasi
5	ART64-27-1-1-B-B	AfricaRice	39	ART101-99-1-2-B-B	AfricaRice	73	CRI-1-21-5-12	CRI-Kumasi
6	ART64-31-1-1-B-B	AfricaRice	40	ART109-24-1-1-B-B	AfricaRice	74	ART58-66-1-1-B-B	AfricaRice
7	ART64-32-1-1-B-B	AfricaRice	41	ART112-74-1-1-B-B	AfricaRice	75	CRI-1-11-19-12	CRI-Kumasi
8	ART64-42-1-1-B-B	AfricaRice	42	ART112-85-1-1-B-B	AfricaRice	76	Sahel 177	CRI-Kumasi
9	ART64-55-1-1-B-B	AfricaRice	43	ART164-73-1-1-B-B	AfricaRice	77	Viwonor short	CRI-Kumasi
10	ART68-12-1-1-B-B	AfricaRice	44	ART71-2-1-1-B-B	AfricaRice	78	KAF53	KAFACI
11	ART75-8-1-2-B-B	AfricaRice	45	ART71-96-1-1-B-B	AfricaRice	79	KAF148	KAFACI
12	ART75-14-1-2-B-B	AfricaRice	46	ART78-30-1-2-B-B	AfricaRice	80	KAF228	KAFACI
13	ART75-33-1-1-B-B	AfricaRice	47	ART86-48-1-1-B-B	AfricaRice	81	KAF239	KAFACI
14	ART75-56-1-2-B-B	AfricaRice	48	ART93-7-1-1-B-B	AfricaRice	82	T-MARSHAL	CRI-Kumasi
15	ART75-57-1-1-B-B	AfricaRice	49	ART93-112-1-1-B-B	AfricaRice	83	TOX3378	CRI-Kumasi
16	ART79-12-1-1-B-B	AfricaRice	50	ART350:6-15-5-B	AfricaRice	84	BOUKE	CRI-Kumasi
17	ART90-6-1-1-B-B	AfricaRice	51	ART350:10-2-1-B	AfricaRice	85	OBOLO	CRI-Kumasi
18	ART90-12-1-1-B-B	AfricaRice	52	ART350:2-4-3-B	AfricaRice	86	GIGANTE	CRI-Kumasi
19	ART90-46-1-1-B-B	AfricaRice	53	ART350:2-6-1-B	AfricaRice	87	N1	CRI-Kumasi
20	ART105-3-1-2-B-B	AfricaRice	54	WAB 2101-WAC4-1-TGR1-WAT3-5-TGR2	AfricaRice	88	N4	CRI-Kumasi
21	ART120-26-1-1-B-B	AfricaRice	55	ART108-2-1-1-B-B	AfricaRice	89	UPL45	CRI-Kumasi
22	ART125-26-1-1-B-B	AfricaRice	56	NERICA -L 19	AfricaRice	90	IR65	CRI-Kumasi
23	ART66-144-1-2-B-B	AfricaRice	57	IR 84105-B-B-B-TGR4	AfricaRice	91	BETIA	CRI-Kumasi
24	ART73-69-1-2-B-B	AfricaRice	58	WAB 2085-TGR2-WAT4-1-1	AfricaRice	92	CRI-AgraRice	CRI-Kumasi
25	ART84-35-1-1-B-B	AfricaRice	59	WAB 2135-WAC B-2-TGR3-WAT8-3	AfricaRice	93	CRI-AMANKWATIA	CRI-Kumasi
26	ART61-52-1-1-B-B	AfricaRice	60	WAB 2138-WAC B-2-TGR2-WAT5-1	AfricaRice	94	IDJA85	CRI-Kumasi
27	ART67-4-1-1-B-B	AfricaRice	61	WAB 2099.WAC1.FKR3-1-TGR1-2	AfricaRice	95	GN/5	CRI-Kumasi
28	ART67-17-1-1-B-B	AfricaRice	62	Local (Sokwai)	CRI-Kumasi	96	TV2	CRI-Kumasi
29	ART67-21-1-2-B-B	AfricaRice	63	AGRA-CRI-LOL-2-27	CRI-Kumasi	97	CK3	CRI-Kumasi
30	ART67-26-1-1-B-B	AfricaRice	64	AGRA-CRI-LOL-2-7	CRI-Kumasi	98	KE40	KAFACI
31	ART67-50-1-2-B-B	AfricaRice	65	AGRA-CRI-LOL-2-29	CRI-Kumasi	99	KE53	KAFACI
32	ART98-4-1-1-B-B	AfricaRice	66	Nerica-L-41	CRI-Kumasi	100	KE99	KAFACI
33	ART98-96-1-2-B-B	AfricaRice	67	AGRA-CRI-LOL-1-11	CRI-Kumasi			
34	ART98-147-1-1-B-B	AfricaRice	68	FAROX 508-3-10-F43-1-1	CRI-Kumasi			

Broken grain (%)

$$= (\text{wt of broken grain}(g) / \text{wt of paddy}(g)) \times 100$$

Milling Degree

$$= \left(\frac{\text{wt of brown rice}(g) - \text{wt of milled rice}(g)}{\text{wt of brownrice}(g)} \right) \times 100$$

Milling Recovery(MRR)

$$= (\text{wt of milled rice}(g) / \text{wt of paddy}(g)) \times 100$$

Head rice recovery(HRR)

$$= (\text{wt of head rice}(g) / \text{wt of paddy}(g)) \times 100$$

One hundred head rice (whole grains from milling) were randomly selected and weighed to determine the weight in grams of hundred head rice per replicate for each genotype.

The degree of chalkiness (DC) was assessed on 10 randomly selected grains of milled rice per replication for each genotype. The grains were placed on a light box and the portion of the chalky area was estimated. The mean of the chalky area of the ten milled rice grains was recorded as the degree of chalkiness. One hundred head rice were randomly selected per replication and placed on light and transparent plate. The grains with chalky area were selected visually and weighed to determine the percentage of grains with chalkiness (PGWC).

$$PGWC = (wtofchalkygrains(g)/wtof100headrice(g)) \times 100$$

The milled rice grain length and width were measured using a vernier caliper on 10 randomly selected milled rice grains of each genotype per replication from the sample. The shape of the milled rice was determined based on the length-to-width ratio (L/W).

$$L/W = (\text{average length of rice}/\text{average width of rice})$$

Statistical analysis

The mean values for all the traits were used for statistical analyses. Analysis of variance for each trait was done by using the Proc mixed of the Statistical Analysis System (SAS) version 9.2 for windows. Genotypes were considered as random effects and replication as fixed effect.

Milling and appearance quality traits and grain yield were used to estimate the genotypic (σ_g^2), environmental (σ_e^2) and phenotypic (σ_p^2) variances according to Burton and Devane (1953). Genotypic variance (σ_g^2) and environmental variance (σ_e^2) were tested using the standard error. The variance components were used to compute the genotypic coefficient of variation (GCV), error coefficient of variation (ECV), the phenotypic coefficient of variation (PCV) according to Falconer (1981), broad-sense heritability (H^2) according to Allard (1960) and expected genetic advance (GA) according to Burton (1952) as follows:

$$\sigma_g^2 = (MSG - MSE)/r$$

where MSG is the mean square of accessions, MSE is mean square of error, and r is number of replications.

$$\sigma_p^2 = (\sigma_g^2) + (\sigma_e^2)$$

$$GCV = \left[\left(\sqrt{\sigma_g^2} \right) / \text{mean} \right] \times 100$$

$$ECV = \left[\left(\sqrt{\sigma_e^2} \right) / \text{mean} \right] \times 100$$

$$PVC = \left[\left(\sqrt{\sigma_p^2} \right) / \text{mean} \right] \times 100$$

$$H^2 = (\sigma_g^2 / \sigma_p^2) \times 100$$

$$GA = K \times H^2 \times \sqrt{\sigma_p^2}$$

The selection differential K was 2.06 at 5% selection intensity.

Genetic advance as percent of mean [GA (%)] was manually calculated in order to visualize the relative utility of genetic advance among the traits as follows:

$$GA(\%) = (GA/\text{mean}) \times 100$$

Correlation coefficients were calculated at both genotypic (r_g) and phenotypic (r_p) levels based on the formulae suggested by Falconer (1981) using the software META-R version 6.0 to determine the relationships among the grain yield and milled rice quality traits:

$$r_g = r(x_i \cdot x_j)_g = \text{Cov} \cdot (x_i \cdot x_j)_g / \sqrt{[v(x_i)_g \times v(x_j)_g]}$$

where $r(x_i \cdot x_j)_g$ is a genotypic correlation between ith and jth traits; $\text{Cov} \cdot (x_i \cdot x_j)_g$ is a genotypic covariance between ith and jth traits; $v(x_i)_g$ is a genotypic variance of the ith trait; $v(x_j)_g$ is a genotypic variance of the jth trait.

$$r_p = r(x_i \cdot x_j)_p = \text{Cov} \cdot (x_i \cdot x_j)_p / \sqrt{[v(x_i)_p \times v(x_j)_p]}$$

where $r(x_i \cdot x_j)_p$ is a phenotypic correlation between ith and jth traits; $\text{Cov} \cdot (x_i \cdot x_j)_p$ is a phenotypic covariance between ith and jth traits; $v(x_i)_p$ is a phenotypic variance of the ith trait; $v(x_j)_p$ is a phenotypic variance of the jth trait.

Results and discussions

Milling properties and appearance quality of the rice accessions

The analysis of variance showed significant differences ($p \leq 0.05$) among the rice accessions under study for all the milled and appearance quality traits of the grain (Table 2) which shows that a huge variability exists among the genotypes for those characters. Thus, the selection of better parental genotypes can be done to improve the milling and appearance quality traits of the rice grain. Coefficient of variation (CV) measures the dispersion of a frequency distribution of a variable. When the CV is high, the grade of distribution around the mean will also be large.

Table 2 Mean square from the analysis of variance of 100 rice accessions evaluated for milling and appearance quality characteristics and grain yield at Fumesua-Kumasi, Ghana in 2018

Trait	Rep (df = 2)	Block (rep) (df = 27)	Genotype (df = 99)	Residual (df = 171)	LSD	CV
Milled grain length	0.11	0.46**	0.51**	0.06	0.27	3.78
Milled grain width	0.07**	0.02**	0.04**	0.01	0.09	3.64
Milled grain L/W	0.17**	0.14**	0.24**	0.03	0.17	5.37
Percentage of grain with chalkiness	1143.84*	1478.50**	2335.67**	307.28	18.60	51.16
Degree of chalkiness	179.65**	79.93**	108.60**	16.05	4.32	39.65
Brown rice recovery	40.90*	20.97**	17.43**	9.72	2.38	4.45
Milled rice recovery	33.01*	23.15**	21.41**	8.92	2.63	4.81
Milling degree	14.97	13.84	17.02*	11.41	2.22	29.61
Head rice recovery	1152.26**	166.04*	173.84**	99.87	7.46	22.63
Broken rice grain	1128.31**	122.55	121.62**	79.69	5.99	49.84
100 Head rice weight	0.43**	0.14**	0.07**	0.03	0.16	9.60
Grain yield per plant	0.49	3.40**	4.99**	1.31	1.16	32.61

*Significant at 0.05 level of probability; ** Significant at 0.01 level of probability

In this study, percentage of grain with chalkiness had the highest CV (51.16%), while milled grain width had the lowest CV (3.64%). Coefficient of variation was low for milled grain length (3.78%), milled grain length-to-width ratio (5.37%), brown rice recovery (4.45%) and milled rice recovery (4.81%). Sahu et al. (2017) reported higher coefficients of variation for brown rice recovery and milled rice recovery. The lower CV observed for brown rice recovery and milled rice recovery in our study might be due to the use of different germplasm and differences in the calibration of the milling machine.

Milled rice recovery ranged from 51.4 to 67.7% with genotypes ART64-42-1-1-B-B, ART58-51-1-2-B-B, ART67-21-1-2-B-B being the top performers (Table 3). Dipti et al. (2003) reported milled rice recovery that ranged from 68.0 to 71.0% in some Beruin rice varieties of Bangladesh. Head rice recovery ranged from 25.3 to 63.1% with three best genotypes ART64-42-1-1-B-B, ART67-21-1-2-B-B and CRI-1-11-19-12. Ravindra et al. (2009) also reported a range of 48.7-67.9% for head rice recovery. Graham Acquah et al. (2018) reported 6 to 66% head rice recovery for 45 rice varieties in West Africa. In the present study, the genotypes that had highest milling recovery and head rice recovery will be useful for farmers and breeders in Africa and beyond.

Based on the degree of chalkiness, genotype KAF53 had the highest value of 34.2%, while genotype CRI-AMANKWATIA had the lowest value of 0.7%. Genotypes CRI-AMANKWATIA and AGRA-CRI-LOL-1-11 will be the most desirable for improving high yielding varieties with high amount of chalkiness. Similar results of 3.0 to 44.0% and 9.0 to 34.0% were reported by Graham-Acquah et al. (2018) in the evaluation of 45 rice varieties in

Benin and Senegal respectively. The lower the percentage of grain with chalkiness (PGWC), the more desirable it is. PGWC ranged from 1.6 to 100%. Genotypes WAB 2135WAC B-2-TGR3-WAT8-3, WAB 2138-WAC B-2-TGR2-WAT5-1, OBOLO, N4 and UPL45 had the highest percentage, while the genotype BETIA had the lowest. Shilpa and Krishnan (2010) reported a PGWC that varied from 24.1 to 85.0% in 22 rice varieties evaluated in India for their milling and appearance characteristics. Genotypes BETIA and CRI-AMANKWATIA had the desirable PGWC and degree of chalkiness, thus, they can be used in the improvement of high yielding varieties with high amount of chalkiness.

Genotypic and phenotypic variances, expected genetic advance and heritability for grain yield, milling and appearance quality traits

The mean performance, genotypic coefficient of variation (GCV), phenotypic coefficient of variation (PCV), environmental variance (σ_e^2), genotypic variation (σ_g^2), phenotypic variation (σ_p^2), heritability (H^2) and genetic advance (GA) for all the traits is presented in Table 3. Significant differences were observed for genotypic and environmental variances among all the rice genotypes for all the studied traits. Among the one hundred rice genotypes evaluated, percentage of grain with chalkiness had the highest genotypic variance of 676.14 and the highest phenotypic variance of 983.42. The milled grain width and hundred head rice weight had the lowest genotypic variance of 0.01, while milled grain width had the lowest phenotypic variance of 0.02. All the milled grain dimensions' parameters (width, length and length-to-width ratio) and hundred

Table 3 Estimate of genetic parameters, broad-sense heritability, genetic advance for milling and appearance quality characteristics and grain yield of 100 rice accessions evaluated at Fumesua-Kumasi, Ghana in 2018

Trait	Mean	Range		σ_g^2	σ_e^2	σ_p^2	GCV (%)	ECV (%)	PCV (%)	H^2 (%)	GA (%)
		Min	Max								
MGrL	6.63	5.64	7.93	0.15 ± 0.02**	0.06 ± 0.01**	0.21	5.8	3.8	7.0	70.6	0.21
MGrW	2.25	1.95	2.65	0.01 ± 0.00**	0.01 ± 0.00**	0.02	4.7	3.6	6.0	62.9	0.02
L/W	2.96	2.32	3.77	0.07 ± 0.01**	0.03 ± 0.00**	0.10	9.0	5.4	10.5	73.8	0.10
PGWC	34.26	1.59	100.00	676.14 ± 112.14**	307.28 ± 30.88**	983.42	75.9	51.2	91.5	68.8	983.42
DC	10.11	0.67	34.17	30.85 ± 5.26**	16.05 ± 1.65**	46.90	55.0	39.6	67.8	65.8	46.90
BRR	70.08	63.00	75.00	2.57 ± 0.95**	9.72 ± 1.00**	12.29	2.3	4.4	5.0	20.9	12.29
MRR	62.06	51.40	67.70	4.16 ± 1.11**	8.92 ± 0.92**	13.08	3.3	4.8	5.8	31.8	13.08
DM	11.41	7.00	22.00	1.87 ± 0.91*	11.41 ± 1.29**	13.28	12.0	29.6	31.9	14.1	13.28
HRR	44.15	25.30	63.10	24.66 ± 9.10*	99.87 ± 10.35**	124.53	11.2	22.6	25.3	19.8	124.53
BroGr	17.91	4.60	34.50	13.97 ± 6.54*	79.69 ± 8.20**	93.67	20.9	49.8	54.0	14.9	93.67
100-HRW	1.87	1.50	2.40	0.01 ± 0.00**	0.03 ± 0.00**	0.05	6.2	9.6	11.4	29.6	0.05
GY	4.46	1.6	7.8	0.64 ± 0.21**	2.13 ± 0.22**	2.54	2.77	17.9	32.7	37.3	23.1

σ_g^2 Genotype variance; σ_e^2 Environmental variance; σ_p^2 Phenotype variance; GCV Genotype coefficient of variation; ECV Error coefficient of variation; PCV Phenotypic coefficient of variation; H^2 Broad sense heritability; GA Genetic advance as percent of mean

MGrL Milled grain length; MGrW Milled grain width; L/W Milled grain length to width ratio; PGWC Percentage of grain with chalkiness; DC Degree of chalkiness; BRR Brown rice recovery; MRR Milled rice recovery; DM Degree of milling; HRR Head rice recovery; BroGr Percentage of Broken rice grains; 100-HRW Hundred Head rice weight; GY Grain Yield

*Significant at 0.05 level of probability; **Significant at 0.01 level of probability

milled grain weight had low genotypic and phenotypic variances, which are indicative of relatively stable nature of these traits (Sahu et al. 2017). The environmental variance for brown rice recovery, milling degree, milling recovery, head rice recovery, percentage of broken rice grain and grain yield were large. This result confirmed the result of Qiu et al. 2015 who reported large environmental variance for head rice recovery, which indicated low phenotypic precision in the measurement of milling quality traits.

Among the evaluated rice accessions, percentage of grain with chalkiness had the highest genotypic coefficient of variation (75.9%) and phenotypic coefficient of variation (91.5%); Brown rice recovery had the lowest GCV (2.3%) and PCV (5.0%). Genetic variability analysis pointed out that the values of PCV were slightly higher than their corresponding GCV estimates for the length, width and length-to-width ratio of the milled grain, percentage of grain with chalkiness and degree of chalkiness. This indicates that phenotypic variation was determined largely by genotype, therefore, selection of those traits on the basis of phenotype only could also be effective. Babu et al. (2012) and Karupaiyan et al. (2013) have reported similar results. The extent of phenotypic coefficient of variation was higher than their corresponding genotypic coefficient of variation for brown rice recovery, milling degree, milling recovery, head rice recovery, percentage of broken rice

grain, hundred head rice weight and grain yield. This may be explained by the higher genotypes by environment interaction for these traits as suggested by Kavitha and Reddy (2002).

Percentage of grain with chalkiness and degree of chalkiness combined high heritability with high genetic advance as percent of mean. This indicates that the environment has a minor influence on the expression of these traits and these traits are controlled by additive gene action as suggested by Panse (1957). Therefore, these traits could be selected by breeders in early generations. High heritability along with moderate genetic advance as percent of mean was observed for milled grain length and milled grain length-to-width ratio. This is an indication that additive gene action governs those traits and selection will be rewarding (Roychowdhury and Tah 2011). High heritability along with low genetic advance as percentage of mean recorded for milled grain width suggested that this trait might be governed by non-additive gene action as indicated by Panse (1957). Panse (1957) suggested that if a trait is governed by non-additive gene action, it may combine high heritability with low genetic advance. A trait that combined high genetic advance with high heritability, suggests that trait is controlled by additive gene action and its selection will be very effective.

Table 4 Estimate of Genotypic and phenotypic correlations of 100 rice accessions evaluated at Fumesua-Kumasi, Ghana in 2018

TRAIT	MGrW	L/W	PGWC	DC	BRR	MRR	DM	HRR	BroGr	100-HRW	GY
MGrL	rp	0.872**	-0.329**	-0.259**	-0.211*	0.005	-0.097	0.026	0.501**	0.043	
	rg	0.890**	-0.383**	-0.400**	-0.296**	-0.063	-0.251	0.130	0.860**	-0.024	
MGrW	rp	-0.788**	0.508**	-0.074	-0.186	0.219*	-0.003	-0.076	0.321**	0.117	
	rg	-0.812**	0.663**	-0.125	-0.276**	0.402**	0.008	-0.177	0.535**	0.164	
L/W	rp	-0.409**	-0.463**	-0.151	-0.060	-0.104	-0.067	0.055	0.169	-0.023	
	rg	-0.457**	-0.528**	-0.205*	-0.064	-0.213*	-0.160	0.182	0.397**	-0.041	
PGWC	rp	0.779**	-0.094	-0.199*	-0.199*	0.218*	-0.046	-0.030	0.255*	-0.110	
	rg	0.892**	-0.168	-0.343**	-0.343**	0.359**	-0.105	-0.048	0.450**	-0.204*	
DC	rp	0.009	0.009	-0.032	-0.032	0.074	0.087	-0.117	0.203*	-0.083	
	rg	-0.143	-0.159	-0.159	-0.159	0.155	-0.026	-0.089	0.497**	-0.083	
BRR	rp	0.804**	-0.012	0.804**	-0.012	0.573**	-0.344**	-0.344**	-0.240*	-0.150	
	rg	0.919**	-0.464**	0.919**	-0.464**	0.801**	-0.556**	-0.556**	-0.263**	-0.434**	
MRR	rp	0.599**	-0.604**	0.599**	-0.604**	0.599**	-0.291**	-0.291**	-0.265**	-0.072	
	rg	0.736**	-0.804**	0.736**	-0.804**	0.736**	-0.444**	-0.444**	-0.351**	-0.134	
DM	rp	0.227*	-0.402**	0.227*	-0.402**	0.227*	0.015	0.123	0.123	-0.071	
	rg	0.402**	-0.402**	0.402**	-0.402**	0.402**	0.116	0.594**	0.594**	-0.311**	
HRR	rp	0.940**	-0.929**	0.940**	-0.929**	0.940**	-0.940**	-0.940**	0.060	-0.061	
	rg	0.929**	-0.185	0.929**	-0.185	0.929**	-0.929**	-0.929**	0.021	-0.212*	
BroGr	rp	-0.185	-0.097	-0.185	-0.097	-0.185	-0.185	-0.185	-0.185	0.042	
	rg	-0.097	-0.184	-0.097	-0.184	-0.097	-0.097	-0.097	-0.097	0.184	
100-HRW	rp	0.019	0.105	0.019	0.105	0.019	0.105	0.019	0.105	0.105	
	rg	0.105	0.019	0.105	0.019	0.105	0.019	0.105	0.105	0.019	

σ^2_e Genotype variance; σ^2_e Environmental variance; σ^2_p Phenotype variance; σ^2_p Phenotype coefficient of variation; σ^2_p Error coefficient of variation; σ^2_p Phenotype coefficient of variation; H^2 Broad sense heritability; GA Genetic advance as percent of mean; $MGrL$ Milled grain length; $MGrW$ Milled grain width; L/W Milled grain length to width ratio; $PGWC$ Percentage of grain with chalkiness; DC Degree of chalkiness; BRR Brown rice recovery; MRR Milled rice recovery; DM Degree of milling; HRR Head rice recovery; $BroGr$ Percentage of Broken rice grains; $100-HRW$ Hundred Head rice weight; GY Grain Yield

Genotypic and phenotypic associations amongst traits

Genotypic and phenotypic correlations between grain yield and milled grain quality traits are recorded in Table 4. Genotypic correlation coefficients were higher than their corresponding phenotypic correlation coefficients for most of the traits under study. Brown rice recovery, milling recovery and head rice recovery had significant positive association among themselves. Nayak et al. (2003) and Nirmaladevi et al. (2015) reported similar associations. But these traits were negatively correlated with milled grain length, percentage of grain with chalkiness, milling degree and percentage of broken rice grain at both phenotypic and genotypic levels. This indicated that the selection based on brown rice recovery, milling recovery and head rice recovery would result in less breakage of the grains. Milled grain length-to-width ratio showed negative association with head rice recovery and positive with percentage of broken rice grains. This indicated that short or short-bold grain genotypes are less susceptible to breakage than long or long-slender grain genotypes. Nirmaladevi et al. (2015) reported similar results. Grain yield was significantly negatively correlated with percentage of grain with chalkiness, brown rice recovery, head rice recovery and milling degree at genotypic level. At genotypic level, grain yield was reported to have significant positive association with brown rice recovery but non-significant negative with head rice recovery (Edukondalu et al. 2017).

Brown rice recovery and milled rice recovery were positively significantly related to head rice recovery, while milled grain length-to-width ratio was negatively related to head rice recovery. Head rice recovery which is a major marketing trait could thus be selected indirectly using milling recovery and milled grain length-to-width ratio.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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