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INFLUENCE OF GENETIC AND GENOTYPE x ENVIRONMENT INTERACTION ON QUALITY OF RICE GRAIN

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ABSTRACT

Rice *(Oryza sativa)* grain attributes, including among others milling quality, grain length and shape, amylose content, and aroma are critical in varietal development and subsquent adoption at the farm level. It is, therefore, important to understand the influence of genetic and G x E interaction on these grain attibutes. Thus, experiments were laid out during 1999-2000 at the Tanganyika Agricultural Cooperative, Ifakara (irrigated culture) and at Sokoine University of Agriculture (upland conditions) both in Morogoro region, to obtain relative magnitudes of variety x environment interactions, heritability and genetic advance aspects on physical and biochemical rice grain quality attributes. High significant positive genotypic and phenotypic correlations were revealed between gel consistency (GC) and both the grain length (GL) and amylose content (AC). Gel consistency had high estimates of heritability and expected genetic advance, and is thus a reliable selection criterion for amylose content in early generations of rice improvement. The observed variation among genotypes under different environments suggest that in order to ensure high grain quality, there is need to select genotypes for particular cropping environments.

Key Words: Genetic advance, heritability, *Oryza sativa*, upland, Tanzania

RÉSUMÉ

Les attributs de riz *(Oryza sativa)*, inclut parmi d'autres la qualité au moulant, la longueur et la forme des grains, le contenu d'amylose, et l'arôme sont importants dans le développement variétal et l'adoption au niveau de ferme. C'est plus important de comprendre l'influence de génétique et l'interaction G x E sur ces attributs de grain. Ainsi, les expériences ont été faites entre 1999-2000 à la Coopérative agricole de Tanganyika, Ifakara (sous culture irrigué) et à l'Université d'Agriculture de Soko¿ne (sur haute terre conditionnée) les deux dans la région de Morogoro, pour obtenir des magnitudes relatives des interactions variété x environnement, héritabilité et les aspects d'avance génétiques sur les attributs de qualité de grain de riz physiques et biochimiques. Les hautes corrélations, significatives et positives entre génotypes et les phénotypes ont été révélées entre l'homogénéité de gel (GC) et la longueur de grain (GL) et le contenu d'amylose (AC). L'homogénéité de gel a eu la haute estimation de héritabilité et l'avance génétique prévue, et est un critère de sélection fiable pour le contenu d'amylose dans toutes les générations d'amélioration de riz. La variation observée parmi les génotypes sous les environnements différents suggère que pour garanti la haute qualité de grains, il y a nécessité de choisir des génotypes particulier pour des environnements différents.

Mots Clés: Avance génétique, héritabilité, *Oryza sativa*, haute terre, Tanzanie

INTRODUCTION

Rice *(Oryza sativa)* grain quality attributes are among important factors prior to variety adoption. They include physical (milling quality, grain length and shape) and biochemical (amylose content, gel consistence, gelatinisation temperature and aroma) characteristics. Such grain quality attributes vary among varieties and production environments (Unnevehr *et al*., 1992;

Jennings *et al.*, 1979; Fan *et al*., 1999). Post harvest factors like rice parboiling, aging or storage for 3-4 months were reported to improve total and head rice (Juliano, 1972). In accordance with the classification by IRRI (1988), extra long (6.61-7.50 mm) to medium (5.51-6.60 mm) grain lengths are preferred in Tanzania. Correlation studies among physical and biochemical characteristics show that grain length have negative associations with grain width and shape (Juliano and Villareal, 1993) and chalkiness (Khush, 1994). Inheritance studies further indicate that grain length is highly heritable, and its inheritance varies from monogenic to essentially polygenic (Mackill *et al.*, 1996).

The level of chalkiness affects milling quality as it provides weaker points for breakage under mechanical milling. Low and high temperatures after flowering, and excess soil fertility in rainfed lowland are factors for increased chalkiness (Resurreccion, 1977). The trait is quantitatively inherited and its mode of inheritance depends on parental and environmental influences (Chang and Somrith, 1979). According to Chang and Somrith (1979) other breeders' experiences show that chalkiness fixes earlier and therefore, strict selection for chalkiness should begin from the early generations.

Amylose is a factor responsible for cooked rice hardness, stickiness, colour, gloss and general acceptability (Mackill *et al.*, 1996). Low ambient temperatures during ripening increase amylose content and decreases with increased nitrogen application (Juliano, 1972; Resurreccion, 1977). Depending on amylose content, rice vary in water requirements and texture after cooking. In Tanzania, intermediate amylose content (21-25%) rice that becomes fluffy when cooked and remains soft when allowed to cool is generally preferred.

Amylose content has been reported to show positive correlations with gel consistency and gelatinisation temperature, but a negative correlation with grain width (Juliano and Villareal, 1993). The inheritance of amylose content was reported to be simple (Mackill *et al.*, 1996). Gelatinisation temperature (GT) was documented to vary with respect to the ratio of amylose to amylopectin, starch crystallinity, granule size, distribution and the amount of minor constituents like phosphorus, lipids, protein and enzymes (Chattakanonda *et al*., 2000). High air temperature after flowering raises GT; while low air temperature lowers it (Mackill *et al*., 1996). Rice with high GT tend to require more water and time to cook than those possessing either low or intermediate GT (Chatterjee and Maiti, 1985). Juliano Rice varieties possessing intermediate GT 70-74^{0}C are preferred in the country. Juliano (1987) also revealed that high GT was associated with low amylose. The inheritance of gelatinisation temperature is, however, simple involving one or two major genes (Shan *et al.*, 1987).

Gel consistency depends on the variations in amylopectin fractions (Juliano and Perdon, 1975). Addition of nitrogenous fertiliser at heading stage somehow increases the protein content, which subsequently contributes to harder gel consistency (Seetanum and De Datta, 1973). Some high GT rice tends to give hard cooked rice and rice products due to the presence of large amylopectin molecules (Perez *et al*., 1979). In Tanzania, soft gel consistency (61-100 mm) is preferred to hard gel consistency.

Effects of environmental factors on rice grain qualities tend to limit the effectiveness of selection of superior genotypes. Genotypes x environment interactions reveal the need for development of genotypes that should be tested and selected for specific growing environments (Mehta *et al.*, 1984; Fehr, 1987).

Tanzania has varied rice growing environments for which recommendations of varieties are being made. Recently, various rice breeding materials of different yield potentials and grain qualities have been developed. Apparently, there is no information on the effect of rice grain qualities due to genotypes x environments (ecosystems) interactions. However, experiments conducted elsewhere are insufficient and not representative of the available genotypes under the existing varied environmental conditions.

The present study was therefore, aimed at evaluating the performance of the new rice genotypes and their interactions on grain quality attributes under varying environments (upland rice and lowland conditions). The specific focus was on assessing the contribution and the relative magnitudes of rice variety and variety x environment interaction on physical and biochemical traits under upland and irrigated ecosystems; and estimating and assessing correlations and genetic parameters of physical and biochemical grain quality attributes and determining their relative importance for rice improvement under upland and irrigated cultures

MATERIALS AND METHODS

The experiment was conducted during 1999-2000 at the Tanganyika Agricultural Cooperatives (TAC), Ifakara (irrigated), and Sokoine University of Agriculture (SUA) Farm (upland) in Morogoro region. Ten rice varieties/lines including SSD1, SSD3, SSD5, M15A, Line85, Line88, TXD275, TXD220 and Supa (control), and some amutant from SUA were used in the study. Seeds tested were selected on the basis of their potential performance for future seed release. The study was laid out in a randomised complete block design (RCBD) with three replications and plot sizes of 4 m x 2 m. Seeds (2 - 3) were dibbled per hill at spacing of 20 cm x 20 cm. Thinning was done to two seedling/plant and the harvested area was 3.5 m x 1.5 m. Weeding, N fertiliser application and other agronomic practices were done as per recommended standards.

Data recorded comprised grain length and width, grain shape and opacity, amylose content, gel consistency, gelatinisation temperature and aroma. A graphic (logarithmic) paper method described by Jennings *et al. (*1979) was used to determine grain size, shape and opacity of each genotype. Amylose content was determined as per modified simplified assay (manual) procedure by Juliano *et al.* (1981). A method as described by Cagampang *et al.* (1973) was used to determine gel consistency of rice genotypes. Opacity of milled rice was visually rated in terms of chalky proportions of the grains. The assessment was done on any chalkiness, whether white belly, white centre or white back. All grain quality attributes results were rated, evaluated and assessed according to the scale established by IRRI (1988).

Statistical analyses were performed per site as well as when pooled over two locations. SAS Software, Version 8.12 (1997) was used for this purpose. Genotypic and phenotypic correlation coefficients were computed by a method proposed by Miller *et al.*, 1958; Steel and Torrie, 1980.

RESULTS AND DISCUSSION

At TAC site which was under irrigated condition, soils were medium acidic clay, with medium Ca^+, Mg^+ and K^+ and low Na^+. Temperatures ranged from 31.5 -27.1^{0}C (maximum) and 23.3 -19.6^{0}C (minimum). At flowering, temperatures ranged from 29.2-28.3^{0}C (maximum) and 23.1-21.7^{0}C (minimum).

A rainfall dependent SUA site had its soils as slightly acidic clay sand with medium Ca^+, K^+ and Na^+ and high Mg^+. Temperatures ranged from 30.6 -17.4^{0}C. Mean rainfall during the entire growing season was about 140 mm month^{-1}.

Performance results of physical and biochemical traits of lines/variety tested are shown in Tables 1 - 4. Environmental means for grain length and amylose content were higher at TAC than at SUA site, but the reverse was true for gelatinisation temperature and gel consistency at SUA than at TAC site.

The significant difference in grain size and non-significant performance in shape among genotypes at TAC and SUA sites suggest differences in inherent genetic characteristics and genotypic responses due to environmental changes over the trait within locations. Similar results on high and less variability of the respective grain size and shape under different environmental regimes have been reported (Unnevehr *et al.,* 1992). Genetic variability has also been reported (Jennings *et al.,* 1979). The significant difference that was depicted on grain shape, when data were pooled, suggests effect of a pronounced environmental influence of grain shape among rice genotypes. Grain size ranged from very long to medium with slender to intermediate shape at TAC, whereas grain size at SUA were long ranged from long to short with intermediate shape. In a combined analysis grain size ranged from long to medium with slender to intermediate shape. Although chalkiness was significant ($P \leq 0.05$), it was regarded as negligible in both the environments tested.

There were significant differences ($P \leq 0.05$) in gelatinisation temperatures among genotypes in all the environments tested (Tables 1 - 3). Except

TABLE 1. Performance of rice varieties/lines on physical traits at Tanganyika Agricultural Cooperatives (TAC) in Tanzania

Variety/line	GL (mm)	Size (mm)	*GL:B ratio	Shape	Chalk.	Opacity	GT	Type	A C	Type	G C	Type
SSD5	7.53ab	Very long	3.31	Slender	1.31cd	Small	4.67b	Interm.	24.28de	Interm.	53.66f	Medium
SSD3	6.70a-c	Long	2.48	Interm.	1.00cd	Small	4.67b	Interm.	24.29de	Interm.	59.33e	Medium
Line85	6.93a-c	Long	2.87	Interm.	3.00ab	Small	1.67c	High	23.33e	Interm.	60.33e	Medium soft
M15A	6.20c	Long	2.58	Interm.	2.33bc	Small	6.33a	Low	30.51b	High	124.67b	Soft
Supa	7.77a	Very long	3.43	Slender	0.33d	None	7.00a	Low	39.38a	High	141.33a	Soft
TXD 275	6.70a-c	Long	2.65	Interm.	4.33a	Small	6.33a	Low	28.71bc	High	104.33c	Soft
Line88	6.40bc	Medium	2.98	Interm.	2.33bc	Small	6.00ab	Low	26.46cd	High	97.67d	Soft
TXD220	7.27a-c	Long	2.38	Slender	3.67ab	Small	6.67a	Low	37.81a	High	127.00b	Soft
SSD1	7.63a	Very long	2.88	Interm.	100cd	Small	4.67b	Interm.	24.58de	Interm.	58.00ef	Medium
M55	7.07a-c	Long	2.88	Interm.	3.67ab	Small	5.67ab	Interm.	24.57de	Interm.	55.33ef	Medium
Mean	7.02	Long	2.85	Interm.	1.76	Small	5.37	Interm.	28.39	High	88.17	Soft
SE	0.40		0.52		0.45		0.48		0.99		1.72	
CV (%)	5.71		18.13		10.24		9.07		3.5		1.95	
R^2	0.72		0.44		0.81		0.94		0.98		0.99	

Means within column followed by the same letter(s) are not significantly different from each other at 5% level. *: GL = Grain length, GL: B = Grain Length:Breadth ratio, Chalk. = Chalkiness, GT = Gelatinization temperature, AC = Amylose content, GC= Gel consistency, Interm. = Intermediate

TABLE 2. Performance of rice variety/lines on physical and biochemical traits at Sokoine University of Agriculture (SUA) in Tanzania

Variety/lines	*GL (mm)	Size (mm)	GL:B ratio	Shape	Chalk	Opacity	GT	Type	AC	Type	GC	Type
SSD5	7.23a-c	Long	2.97	Interm.	0.67cd	Small	5.67bc	Low	25.03b	High	58.33f	Medium
SSD3	6.53b-d	Medium	2.63	Interm.	1.00b-d	Small	6.00a-c	Low	25.58b-d	High	60.00f	Medium
Line 85	6.93b-d	Medium	2.83	Interm.	2.33a-c	Small	6.33ab	Low	28.56ab	High	74.67e	Medium soft
7M15A	6.30cd	Medium	2.87	Interm.	2.67ab	Small	6.33ab	Low	28.26ab	High	130.00bc	Soft
Supa	7.43ab	Long	3.20	Slender	0.00d	None	7.00a	Low	26.74b	High	149.33a	Soft
TXD 275	5.90d	Short	2.40	Interm.	3.00ab	Small	6.33ab	Low	25.47b-d	High	122.33c	Soft
Line 88	6.23cd	Medium	2.68	Interm.	0.67cd	Small	6.33ab	Low	26.92ab	High	104.33d	Soft
TXD 220	7.33cd	Medium	3.22	Slender	4.00a	Small	6.33ab	Low	32.19a	High	135.33b	Soft
SSD1	7.60a	Very long	2.89	Interm.	0.67cd	Small	5.00c	Intermediate	23.33b	Interm.	59.33f	Medium
M55	7.00a-c	Long	2.98	Interm.	1.33b-d	Small	6.00a-c	Low	26.82ab	High	97.33d	Soft
Mean	6.72	Medium	2.96	Interm.	1.63	Small	6.13	Low	26.90	High	99.07	
SE	0.36		0.52		0.14	Small	0.46		1.86		2.73	
CV (%)	5.35		18.36		11.94	Small	7.42		6.70		2.76	
R^2	0.81		0.31		0.97		0.67		0.72		0.99	

Means within column followed by the same letter(s) are not significantly different from each other at 5% level. *: GL = Grain length, GL: B = Grain Length:Breadth ratio, Chalk. = Chalkiness, GT = Gelatinization temperature, AC = Amylose content, GC= Gel consistency, Interm. = Intermediate

TABLE 3. Performance of rice varieties/lines on physical traits averaged combined over two locations (TAC and SUA) in Tanzania

Variety/lines	*GL (mm)	Size	GL:B ratio	Shape	Chalk.	Opacity	GT	Type	A C	Type	G C	Type
SSD5	7.38ab	Long	3.14ab	Slender	1.00cd	Small	5.17e	Interm.	24.66fg	Interm.	56.00i	Medium
SSD3	6.62cdef	Long	2.56b	Interm.	1.00cd	Small	5.33de	Interm.	24.93fg	Interm.	59.67h	Medium
Line85	6.77cde	Long	2.85ab	Interm.	2.67b	Small	4.00f	Interm.	25.95de	High	67.50g	Medium soft
M15A	6.25f	Medium	2.73ab	Interm.	2.50b	Small	6.33bc	Low	29.39c	High	127.30c	Soft
Supa	7.60a	Very long	3.31a	Slender	0.17d	Small	7.00a	Low	33.06b	High	145.30a	Soft
TXD275	6.30ef	Medium	2.68ab	Interm.	3.67a	Small	6.33bc	Low	27.09d	High	113.30d	Soft
Line88	6.32def	Medium	2.78ab	Interm.	1.50c	Small	6.17bc	Low	26.69de	High	101.00e	Soft
TXD220	6.80cd	Long	2.94ab	Interm.	3.83a	Small	6.50ab	Low	35.00a	High	131.02b	Soft
SSD1	7.62a	Very long	2.88ab	Interm.	0.83cd	Small	4.83e	Interm.	23.95g	Interm.	58.67hi	Medium
M55	7.03bc	Long	2.93ab	Interm.	2.50b	Small	5.83cd	Interm.	25.73d-g	High	76.17f	Medium soft
Mean	6.87	Long	2.85	Interm.	1.67	Small	5.75	Interm.	27.65	High	93.62	
SE	0.38		0.52		0.23		0.47		1.49		2.28	
CV (%)	5.54		18.23		14.04		8.20		5.38		2.44	
R^2	0.78		0.38		0.82		0.91		0.93		0.99	

Means within column followed by the same letter(s) are not significantly different from each other at 5% level. *: GL = Grain length, GL: B = Grain Length:Breadth ratio, Chalk. = Chalkiness, GT = Gelatinization temperature, AC = Amylose content, GC= Gel consistency, Interm. = Intermediate

TABLE 4. Genotypic (top) and phenotypic (bottom) correlation of some rice grain qualities from ten rice variety/lines (n=60) combined from TAC and SUA in Tanzania

Trait	Grain length	Shape	Chalkiness	Gelatinisation temperature	Gel consistency	Amylose content
Grain length	1.00					
Shape	-0.28* (-0.27*)	1.00				
Chalkiness	-0.37**(-0.39**)	-0.13 (-0.13)	1.00			
Gelatinisation temperature	0.21(0.24)	-0.25 (-0.24)	0.13(0.12)	1.00		
Gel consistency	0.58**0.65**	0.210.22	0.170.21	0.190.20	1.00	
Amylose content	0.58** (0.50**)	0.23 (0.25*)	-0.05 (-0.04)	-0.43** (-0.48**)	0.57**0.62**	1.00

* Significant at 5% level; ** Significant at 1% level

for Line 85 at TAC, which had high gelatinisation temperatures, the rest demonstrated intermediate to low GTs at SUA and when data were combined. Most entries recorded low gelatinisation temperature (GT) at SUA than at TAC, and this was due to temperature differences between locations. Results imply that variations in GT could be influenced by genetic differences and the genotypic differential responses within and between locations. Similar findings on genetic variability in rice have been documented (Fan *et al.*, 1999), while influences of high or low temperatures above or below 30^0C - 33^0C during flowering have been documented to cause differential low and high gelatinisation temperature, respectively (Yoshida, 1981; Mackill *et al.*, 1996). The GT values in all the locations ranged from 1.67 (low) only for Line 85 to 7.00 (low) for Supa at TAC and 5.00 (intermediate) to 7.00) at SUA. Similarly, GT were 4.00 for Line 85 to 7.00 for Supa when data were pooled.

Significant ($P \leq 0.05$) differences on amylose content among tested genotypes were realized from TAC and SUA sites, even when data of two locations were pooled (Tables 1 - 3). Amylose content among genotypes ranged from 23.33-39.38 for Line 85 and Supa varieties at TAC, 23.33-32.19 for SSD1 and TXD 220 at SUA sites all falling between high to intermediate types (Tables 1 - 3). Variations in amylose content suggests the existence of genetic variabilities. Genetic effects on the performance of amylose content in rice have been reported elsewhere (Mackill *et al.*, 1996), while amylose content increase due to increases in temperature up to 29^0C, above which amylose content decline was documented (Resurreccion *et al.*, 1977).

Significant differences ($P \leq 0.05$) in gel consistency among tested genotypes were obtained from TAC and SUA sites and when data were pooled up (Tables 1 and 2). Gel consistency among varieties ranged from 53.66-141.33 at TAC and at SUA sites and from 56.00-145.30 when data were combined. From all the sites and in the combined analysis, maximum and minimum ranges were obtained from the respective SSD5 and Supa varieties. Higher values were noted at TAC than at SUA.

Results from treatment means and the combined analyses of variance revealed that rice varieties, environments and variety x environment interaction were probable key attributes to the differential performance of gel consistency (Table 3). Differences in performance in gel consistency of rice varieties suggest the existence of genetic variability. Juliano and Perdon (1975) reported a similar finding on existence of genetic variability on the performance amylose content in rice genotypes. All genotypes tested possessed medium gel (41-60 mm) to soft gel consistency (>80 mm) and differences due to temperature and soil moisture regimes among rice varieties.

Since rice with long to intermediate grain size, with slender to intermediate shapes that are translucent with low to intermediate gelatinisation temperature, high amylose content and soft gel consistency are preferred, results suggest that the rice breeding materials tested are likely to be adopted for cultivation in Tanzania (Tables 1 - 3).

From the combined analysis of variance (Table 5), genetic variance was higher than location and genotype x environment interaction variances for all the characters except for gelatinisation temperature. There were no environmental influences on grain length, grain size and chalkiness. Although environmental variance component was unimportant to grain shape, the genotype x environment was very important for gelatinisation temperature, amylose content, and gel consistency, suggesting that environmental factors were also responsible for the modification of amylose. Similar results on the influence of temperatures below/beyond an optimum 30 ^{0}C-33^0 C were also reported to decrease or increase gelatinisation temperature (Mackill *et al.*, 1996) and gel consistency.

Inconsistent treatment results have demonstrated the importance of environment in the general performance of all the traits except for grain shape. The scenario signals difficulties in selection of all the traits evaluated. A more systematic approach aimed at separating environmental effect from genetic component is required to predict success in selection during crop improvement. Results of genotypic and phenotypic correlations of a combined analysis are given in Table 4. Amylose content was negatively and significantly (P<0.01) correlated with gelatinisation temperature, but positively and significantly (P<0.01) correlated with gel consistency. This implies that improving amylose content would simultaneously increase gel consistency, while discriminating gelatinisation temperature. Positive correlations between amylose content with gel consistency and negative correlations with gelatinisation temperature have been obtained from world rices (Juliano and Villareal, 1993).

Results of variance components for grain quality characters of ten genotypes combined over two environments are shown in Table 5. The genetic variance was higher than location and genotype x environment interaction variances for all the characters, except for gelatinisation temperature. However, genotype x environment was very important for amylose content, gelatinisation temperature and gel consistency suggesting influence of environmental changes in performance of the three mentioned rice traits.

From the variance components for grain quality attributes over two locations, all traits had high heritability except for grain shape. Amongst them, gel consistency was the only trait that was observed with both highest broad sense heritability and expected genetic advance. In addition, the trait exhibited significant positive genotypic and phenotypic correlation coefficients with amylose content, which also is the most important trait that greatly determines the eating quality of rice.

CONCLUSION

Environments appreciably affect the performance of rice genotypes and retard selection progress

TABLE 5. Combined analysis of variance (ANOVA) for different physical and biochemical characters of some rice varieties/lines over two locations (TAC and SUA)

Source of variance	Df	Grain length	Grain length:breadth ratio	Chalkiness	Gelatinisation temperature	Amylose content	Gel consistency
Replication	2	0.315	0.014	0.093	0.200	1.334	36.867
Location/environment (E)	1	1.380	0.002	0.622	8.817*	33.555*	1782.150**
Error (a)	2	0.391	0.536	0.052	0.467	1.099	5.400
Genotypes (G)	9	1.651***	0.345	0.828***	4.935***	82.811***	6960.261***
G x E	9	0.162	0.202	0.090	3.187***	36.867***	217.965***
Error (b)	36	0.145	0.270	0.055	0.222	2.214	5.207
Total	59						

* Significant at 5% level ** Significant at 1% level

for grain quality improvement. Despite their inconsistent performance for grain quality traits over two contrasting environments, all tested genotypes possess a wide range of acceptable grain quality attributes and, therefore, stand a chance of being adopted by rice farmers and consumers in Tanzania. In terms of genetic values of the rice traits, rice breeders should consider gel consistency as a reliable indirect selection criterion for amylose content improvement in early generations of rice breeding program.

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