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Full Length Research Paper

Diversity in grain physico-chemical characteristics of West African rice, including NERICA genotypes, as compared to cultivars from the United States of America

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Landraces from West Africa (WA), NERICA progenies derived from crosses between *Oryza sativa* and *Oryza glaberrima,* and improved *O. sativa* lines from Africa Rice Center were introduced to the Beaumont Rice Research Center in Texas, United States of America (USA) (29°57' N and 94°30' W) for in-situ evaluation and characterization. Milled samples of rice produced in Côte d'Ivoire (CI) (7.5° N - 8.5° N and 4.5° W and 5.5° W) were also introduced for chemical analysis. RVA profiles showed that Jaya has unusually strong paste viscosity features. Apparent Amylose content varied from 15% for Khao Dawk Mali 105 originally from Thailand, to 26% for CG 14, an *O. glaberrima* type. WAB 56-104, an improved *O. sativa* variety from Africa Rice Center, had the longest cooking time of 24 minutes. Jaya can be compared to Dixiebelle, a USA variety grown commercially under contract for the canning and processing industries. Total milling yield varied from 78% for Gnanle Gnan-Man, a landrace from WA, to 70% for the USA check Saber. Sierra, a USA check, had the highest value of 2-AP (1258 ng/g), followed by Bakue Danane and Cocote, both from CI. Comparing WA samples grown in CI with those grown in Texas, cooking and pasting parameters were not generally strongly affected by the environment. The variable most affected by environment was the setback which predicts the hardness of cooked rice. Diverse sources for grain quality traits were found in WA germplasm for use in the USA.

Keywords: West Africa, NERICA, *Oryza sativa, Oryza glaberrima*, characterization.

INTRODUCTION

Most of the rice produced in the world is consumed as whole grain and the grain physical and chemical characteristics are therefore very important. There are different market classes of rice that are defined by a matrix of traits which include grain dimensions, grain chemistry, and grain appearance (Webb, 1991). *Long Grain Rice* has kernels which are 3 to 4 times longer than their width and relatively high amylose content (>20%) which causes the grains to remain separate after cooking. In the USA, certain *long grain* cultivars (e.g., Rexmont, Dixiebelle) with high amylose content (>24%) are recommended for canning purposes. *Medium Grain Rice* has kernels that are 2 to 2.9 times longer than their

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width and relatively low (16-18%) amylose content. *Short Grain Rice* has grain that is almost round with the kernels being 1.9 times longer than their width. (Kelly, 1985) reported that medium and short grains are used for products that are served cold. *Glutinous Rice* is also called *Sweet* or *Waxy Rice* and the kernels are completely opaque white. *Aromatic Rice* possesses a natural flavor that is similar to buttered popcorn in aroma. The most popular types of aromatic rice are Basmati from India and Pakistan and Jasmine from Thailand. The primary chemical components of the grain are starch, protein and lipids. According to Kelly (1985), these components determine how the rice whole grain, flour, or starch can be used.

Milling yield of rice is considered to be the most important component of quality (van Ruiten, 1985; Adair et al., 1973; Spadaro et al., 1980). In the USA, a one percent change in breakage can cause a $100,000 difference in profit for an average-sized rice mill (Hosney, 1998).

Cultivars grown in the world have variable cooking, sensory and processing qualities. Many chemists began to look into these cultivar differences in rice end-use in the twentieth century. The primary work on grain quality was conducted by Warth and Darabsett (1914) who studied the rice kernel response to dilute alkali. In the USA, three categories of rice - long, medium and short grain types - were found (Adair et al., 1973). Progress was made in the USA since the inadvertent release of typical long-grain rice Century Patna 231 in the 1920s. Century Patna 231 had the dimensions of typical U.S. long-grain rice. Unfortunately, it had different cooking and processing characteristics. It was a financial disaster for the rice industry. In the 1950s, criteria were established by the rice industry in the USA. These criteria must be met before the release of any cultivar (Mackill and McKenzie, 2003). In collaboration with other scientists, mainly chemists, all selected cultivars in the USA for release fall within a specialty type or defined market classes (long, medium and short grain). It is then certain that the only quality types that people in the industry see are within a defined set of quality traits and the total amount of variation which exists in the germplasm around the world can be under-appreciated (Bergman et al., 2004).

According to (Buddenhagen, 1978) “rice is not only Asian, rice is also African”. However, the cultivated Asian rice *Oryza sativa* (L) is different from *Oryza glaberrima* Steudel, the African rice that was selected by farmers and has been grown in a diverse range of habitats in West Africa for several thousands of years (Carney, 2000). Rice cultivation ecology in Africa is highly diverse compared to the USA where irrigated rice is dominant. Cultivars in Africa also have a range of genetic variation. They comprise the two cultivated species - *O. sativa* L. and *O. glaberrima* Steud. - and their interspecific progenies called New Rice for Africa (NERICA), which have been developed by the Africa Rice Center and its partners. Some studies have already been conducted on the grain quality of *O. glaberrima* and NERICA cultivars. NERICA lines showed tremendous variability for cooking, sensorial and nutritional values. Results from the studies conducted by (Kishine et al. 2008) showed that NERICA varieties with high amylose content (29%) inherited the gene from the glaberrima parents while the lower amylose content (22%) varieties received the gene from the sativa parents. Watanabe et al. (2002) studied *O. glaberrima* lines, interspecific progenies and *O. sativa* lines and concluded that the progenies were superior to *O. glaberrima* parents based on the following traits: husking yield, milling yield, whiteness and translucency of milled rice. These selected references showed that germplasm from Africa needs to be further screened for different quality traits across different environments.

Although rarely mentioned in Africa as a constraint, rice quality is considered the second most important problem after grain yield. Rice production in Africa is becoming more market-oriented where quality becomes a major issue, and quality is considered as an important character in the breeding program of Africa Rice Center. In some African countries, basic grain quality data are available in official documents (e.g. MINAGRA 1998).

Although rice yield and production are increasing in the USA, there are other challenges for USA rice production (Rutger and Bollich 1991; Mackill and McKenzie 2003):

Maintenance of stringent quality criteria for conventional long, medium, and short grain market classes

Identification of novel grain properties that may allow product diversification in the market

Decreasing the cost of production for farmers – for example water usage

Being able to compete with imports on price and quality.

Characterization of foreign germplasm may help the USA’s rice breeding efforts to identify novel traits and incorporate these traits into USA breeding pools. An evaluation of West African germplasm that has previously not been introduced into the USA may reveal genetic resources that have unique quality traits (i.e. rice with slow digestibility) or are tolerant of reduced water usage (i.e. upland rice).

This study evaluated West African (WA) and USA checks for physico-chemical grain quality traits in order to identify characteristics that can benefit rice breeding programs in:

- better understanding of germplasm quality characteristics from WA;

-examining if grain quality characteristics of WA cultivars are stable if rice is grown in the USA and in their birthplace;

- finding novel grain quality traits which widen genetic resources in the USA.

MATERIALS AND METHODS

Landraces from WA, interspecific progenies of crosses between *O.sativa* and *O. glaberrima,* and improved lines from Africa Rice Center and other research centers were introduced to the Beaumont Rice Research Center in Texas, USA for in-situ evaluation and characterization. Milled samples of rice produced in Côte d'Ivoire in WA were also introduced for chemical analysis. The different evaluations will benefit both the USA and WA breeding programs to enhance grain quality characteristics.

Description of the Experiments

Experiment 1 at Beaumont, Texas

Site: The field experiments were conducted at the Texas A&M University System Agricultural Research and Extension Center, in collaboration with the USDA-Agricultural Research Service at Beaumont, TX. The Center is located at 29°57' N and 94°30' W. The field experiments were conducted during the 2004 cropping season. The soil at the Station is an Entic Pelludert (fine, montmorillonitic, and thermic), with a sand, silt and clay composition of 3.2, 32.4 and 64.4, respectively (Texas A&M University 1971). The average annual rainfall is 1473 mm.

Description of the Materials

The field experiment consisted of 17 landraces collected from the western region of Côte d'Ivoire, 7 improved sativa developed at Africa Rice Center or introduced from other research centers, 7 NERICA interspecific progenies from crosses between *O. sativa* and *O. glaberrima* developed at Africa Rice Center and 12 US checks (Table 2). The seeds were received from Africa Rice Center and increased at Puerto Rico. Materials which showed differences in grain shape within the landraces were separated into two by adding a number to the local names before the seeds were increased. Examples: MOLUBA KOLE 33459 and MOLUBA KOLE 33460 originated from the same landrace MOLUBA KOLE.

Raising of the Materials

The experimental plots in Beaumont consisted of 3 rows that were 4.57 m long with a row spacing 17.78 cm. Fertilizer was applied at the rate of 33.7 kg ha^{-1} of N-P-K (0-30-0) pre-plant, 56.2 kg ha^{-1} of urea at planting, 90 kg ha^{-1} of urea at tillering, and 78.7 kg ha^{-1} of urea at the panicle development stage.

Roundup herbicide was applied prior to planting at a rate of 946 ml ha^{-1}. This was followed by Stam 80edf at 3.37 kg ha^{-1}, Bolero at 2.34 l ha^{-1}, and Basagran at 1.75 ha^{-1} applied at the 2-3 leaf stage for broad spectrum weed control. The insecticide Karate Z was applied at a rate of 0.146 l ha^{-1} after permanent flood for control of rice water weevil and the fungicide Quadris was applied at a rate of 0.73 l ha^{-1} at pre-panicle differentiation for control of sheath blight disease.

Methods of Quality Analysis

The following analyses were performed with the cultivars grown at Beaumont: Alkali Spreading Value (ASV), Apparent Amylose Content (AA), Soluble Amylose (SA), Rapid Visco Analyzer (RVA), Cooking time, Protein, Aroma, Milling percent, and Grain dimensions.

Alkali spreading value (ASV)

The method used for ASV involved the visual observation of the degree of dispersion of grains of the milled rice after their immersion in 1.5% or 1.7% KOH. The method was developed by (Little et al. 1958).

Alkali digestion can determine indirectly the gelatinization temperature (GT). The scoring method was visual and based on the method of (Jennings et al. 1979).

Apparent Amylose (AA)

Procedures as described by (Juliano 1971) and (Webb 1972) were used to determine apparent amylose content. The milled samples were individually ground through a 0.40 mm screen using a cyclone sample mill model no 3010-018 UDY mill (UDY, Fort Collins, Colorado, USA). An auto-analyzer 3 (model AA3; Bran and Luebbe, Roselle, IL) was used to determine the apparent amylose content using an automated analyzer control and evaluation software AACCE Version 5.24 (Bran and Luebbe, Roselle, IL,). Laboratory checks known for high and low amylose content were used: Dixiebelle (25% amylose), Gulfmont (22%), Bengal (17%), and Mochi (0%). The average of two replications was used as the apparent amylose content values.

Soluble Amylose Content and Insoluble amylose (SA –IA)

The measurement of rice soluble amylose is a value of the amylose content of hot-water-solubles. It is essentially the same method as in determining the amylose content, except that the flour is not dispersed in alkali but extracted in hot water. The details of the methods can be seen in (Shanty et al. 1980). The insoluble amylose (IA) was calculated by subtracting the soluble amylose from the apparent amylose.

Rapid ViscoAnalyzer (RVA)

The rice samples were milled and ground using the method described previously. Paste viscosity was determined on a Rapid ViscoAnalyzer (RVA) instrument using the American Association of Cereal Chemistry (AACC 1995) Standard Method 61-02

Differential Scanning Calorimetry (DSC6)

Differential scanning calorimetry experiment was conducted using DSC6 (Perkin-Elmer Corp., Norwalk, CT). The software used with the computer was the Pyris series Thermal Analysis Manager Suite N537-0605 Version 4.0. Before any experiment was conducted, the Dixiebelle variety was run as a standard. A sample of 160 mg of rice flour was weighed and 320 µl of deionized water was gently added to it in a polystyrene weighing dish. The sample was mixed with water and a 1- ml syringe was used to collect 0.1 ml of mixture and inserted into the instrument. The onset (To), peak (Tp), conclusion (Tc) and enthalpy (ΔH) of gelatinization were calculated automatically by using the program “Pyris” indicated earlier. The gelatinization temperature range (Tr) can be calculated as [2(Tp-To)] as described by (Krueger et al. 1987)

Milled rice Cooking Time (CT)

Minimum cooking time is defined as “the amount of time in minutes required for gelatinizing the starch in 90% of the kernels” (Ranghino 1966). This is determined by kernels being cooked in excess water and then sampled every minute during cooking, starting at 10-14 minutes, until 9 out of 10 kernels show no ungelatinized starch.

Milled Rice Crude Protein Determination

Each rice sample was weighed in duplicates. The protein content was determined by a nitrogen gas analyzer (model 528; LECO). A factor of 5.95 was used to convert nitrogen % to protein. The method was based on the Official Method 990.03 (AOAC 1995).

Aroma Content - Quantification of 2-Acetyl-1-Pyrroline by Gas Chromatography with Conventional FID Detection

Rapid solvent method for extracting 2-AP was reported by (Bergman et al. 2000). Extraction and quantification of 2-AP is accomplished by weighing 0.3 gm of 20 mesh ground rice to a 12 x 32 mm crimp top vial. Stock solution (0.5 ml) containing w\v = 458.5 ng/ml TMP in methylene chloride is added to the crimp top vial and the vial is sealed. Extraction is performed at 85 ^{o}C for 2.5 hours. Vial contents are analyzed by gas chromatrography.

Milling Experiment

Total and whole milled rice were determined for each sample. An initial amount of 125 g of clean rough rice was weighed and the moisture content recorded. The different samples were milled using the McGill#2 mill for 1 minute. The adjusted total weight at 12% moisture content was determined. Broken kernels were removed using sieves and then the amount of whole milled rice was determined.
Adjusted weight at 12% = [(100- moisture content of sample)/88]
Percent mill = (Adjusted weight/125)*100.

Grain Dimensions

Grain dimensions were measured using the WinSEEDLE scanner machine. Rough rice was dehulled using the Satake dehuller and broken rice was removed using the sieve#10. The seeds were poured into the appropriate tray and the rubber-tipped forceps were used to make sure none of the seeds were touching. The lid of the scanner was closed and a digital image was saved of the sample (WinSEEDLE 2005). A resolution of 400 dpi (dots per inch) was used during the scanning. A Regent Positioning System was used to choose the exact area on the scanner where the sample was placed and then scanned. The recommended menu filters were used to remove objects with an area less than 3 mm^2 and greater than 200 m^2.

Experiment 2 at Mbé, Bouaké, Côte d'Ivoire

Site Description

The rice samples introduced from WA were grown at Mbé, Côte d'Ivoire located between 7.5^o N and 8.5^{o}N and between 4.5^o W and 5.5^o W (WARDA 2005) where the average annual rainfall is 985 mm. The station is characterized by three main seasons: a long dry season which starts in early November and ends in mid-March; a long rainy season from mid-March to mid-July; a short rainy season from mid-July to mid-August, and an inter-season rainy period from mid-August and to October.

Description of the Materials

The experiment consisted of 18 landraces collected from the western region of Côte d'Ivoire, 13 improved sativa developed at Africa Rice Center or introduced from other research centers, 7 NERICA (interspecific progenies derived from crosses between *O. sativa* and *O. glaberrima*) developed at Africa Rice Center and 1 *O. glaberrima* accession (Table 4).

Raising of the Materials

At Mbé, rice was transplanted when the seedlings were 3 weeks old. Fertilizer was applied at 75 kg ha^{-1} TSP plus 75 kg ha^{-1} of urea as basal. The first top dressing was applied 30 days after transplanting (DAT) at 50 kg ha^{-1} of urea. At 45 DAT, 50 kg ha^{-1} of urea was applied as second-top dressing and the same amount at 70 DAT as third-top dressing. For weed control, gramoxone was applied at 3 l ha^{-1} 3 days before transplanting and ronstar at 5 l ha^{-1} after transplanting.

Methods of Quality Analysis

Alkali Spreading Value (ASV), Apparent Amylose Content (AA), Rapid Visco Analyzer (RVA), Differential Scanning Calorimetry (DSC), and Cooking time were determined using the same methods as described in experiment 1.

Statistical Analysis

The procedure PROC GLM from SAS (2002) Version 9.0 was used to estimate differences between the means of the different variables. Paired comparisons were used to compare the results from Mbé and Beaumont. A dendrogram was drawn using the software Multivariate Statistical Package (MVSP 3.1) for cluster analysis.

RESULTS

Experiment 1 at Beaumont, Texas

Physico-Chemical Analysis of Cultivars Introduced from Africa Rice Center and Grown in a USA Environment

Milling Characteristics of the West African Cultivars Grown in Beaumont

Total milling yield varied from 78% for Gnanle Gnan-Man, a landrace from WA to 70% for the USA check Saber (Table 1). Whole mill yield varied from 70% for Bengal to less than 40% for ZHE733, both checks from the USA. Bengal and NERICA 3 had both a superior total and whole milling yield.

Grain Quality Properties of the West African Cultivars Grown in Beaumont

Grown in the USA environment, materials from WA showed variability for different traits that define the quality of rice. The African materials were characterized by an apparent amylose content that varied from 19.8% for Bakue Danane to 25.3% for NERICA 1 (Table 2). The USA materials varied from 10.6% for Bengal to 25.3% for Sierra. For the overall experiment, the soluble amylose content varied from 5.6% for Bengal to 16.3% for Cheniere. The insoluble amylose content varied from 4.9% for Bengal to 13% for Jaya. The majority of the cultivars had more soluble amylose than insoluble amylose, but varieties like BG 90-2, Saber, Baldo, and ZHE733 had equal amounts soluble amylose and insoluble amylose whereas Jaya had more insoluble amylose than soluble amylose. ASV varied from 3.1 for Cocodrie to 7 for Jaya and BG 90-2. The cultivars were characterized by intermediate to low GT. CT varied from 14 minutes for Jasmine 85, a US check, to 23.5 min for Moluba Kole, a landrace from WA.

Zhe733, Jaya, Cheniere, and NERICA 2 had the highest protein content (9.0%) whereas Lognini Court had the lowest (5.8%). Regarding the RVA curve, Jaya had the highest peak value (369 RVU) while Cheniere had the lowest (183 RVU) even though both had similar amylose contents. Jaya had a high peak, a low Bkdn and a low Stbk.

BG 90-2 had an intermediate peak, but a high Cool and high Stbk. A high Stbk represents a high increase in viscosity during Cooling (Table 2). The interspecific lines had intermediate Peaks and NERICA 2 had a relatively high Stbk (58 RVU). WA materials were characterized by intermediate to long grain types with only two cultivars (Gnokou Gnokou and Gninni Zeba) having short grains.

Table 1. Means of the milling and grain dimensions and cooking time of the cultivars introduced from West Africa and USA checks grown in Beaumont.

No	Varieties	Total %	Whole %	Grain Length (mm)	Grain Width (mm)	Grain Length Width ratio	Cooking Time (min.)
25	Gnanle Gnan-Man-33416	78 a	55.42 ghij	6.52 qr	2.67 cd	2.43 i	22.26 b
41	Baldo	77.12 ab	55.47 ghij	7.11 ghij	3.08 a	2.30 k	22.40 ab
32	Bengal	76.60 abc	70.37 a	6.51 qrs	2.67 cd	2.43 i	19.90 hijkl
39	Nerica 2	76.52 abc	64.87 bcd	7.17 fghi	2.43 i	2.94 g	22.00 bc
16	Mahafin	76.46 abcd	56.26 ghi	6.13 u	2.63 de	2.32 jk	19.66 ijklm
40	Nerica 5	76.20 abcde	64.10 bcd	6.93 kl	2.23 mn	3.10 de	29.23 bcdefgh
43	ZHE733(BMT)	76.15 abcde	36.90 m	6.69 nop	2.54 fg	2.62 h	21.43 gbcdef
35	Nerica 1	76.02 abcdef	57.40 efgh	6.96 jk	2.40 ijk	2.89 g	20.23 efghijkl
15	Mokossi	76.00 abcdefg	57.62 efg	6.33 t	2.62 de	2.41 ij	20.20 fghijkl
37	Nerica 3	75.97 abcdefg	67.72 ab	7.05 hijk	2.42 i	2.90 g	20.96 bcdefghi
6	Moluba kole-33460	75.82 bcdefg	59.07 efg	6.80 lmn	2.53 fgh	2.68 h	21.66 bcde
36	Nerica 4	75.72 bcdefgh	66.50 ab	7.02 ijk	2.41 ij	2.91 g	21.03 bcdefghi
11	Yablo	75.40 bcdefghi	57.60 efg	6.68 nop	2.72 c	2.45 i	21.46 bcdef
34	Nerica 7	75.15 bcdefghij	56.87 efgh	7.59 bc	2.49 fghi	3.05 ef	23.53 a
29	Sierra	75.12 bcdefghij	64.32 bcd	7.77 a	2.44 i	3.19 cd	20.50 defghijkl
42	ZHE733	75.00 bcdefghij	35.70 m	6.78 lmno	2.56 ef	2.64 h	21.50 bcdef
31	Cheniere	74.95 cdefghijk	66.72 ab	7.35 de	2.10 p	3.49 a	19.33 jklmn
13	GnanleGnan-Man 33417	74.70 cdefghijk	57.65 efg	6.41 rst	2.72 c	2.35 ijk	21.90 bcd
19	WAB 638-1	74.67 cdefghijk	66.15 abc	6.36 rst	2.13 op	2.98 fg	16.76 r
33	COCODRIE	74.57 cdefghijkl	65.00 bcd	7.35 de	2.26 lmn	3.24 bc	21.26 bcdefgh
17	Bakue Danane	74.57 cdefghijkl	66.05 abc	6.17 u	2.12 op	2.90 g	17.50 qr
7	Jaya	74.33 defghijklm	46.03 l	6.50 qrs	2.64 cd	2.46 i	17.73 qr
18	Cocote	74.32 defghijklm	64.42 bcd	6.15 u	2.13 op	2.88 g	17.33 qr
2	Lognini court	74.17 efghijklm	57.02 efgh	6.68 nop	2.54 fg	2.62 h	20.30 efghijkl

Means with the same letter within the same column are not statistically different.

Table 1. Continued

No	Varieties	Total	Whole	Grain Length (mm)	GrainW (mm)	GrainL/W ratio	Cooking Time (min.)
38	WAB 56-104	73.92 fghijklm	59.17 efg	7.68 ab	2.46 hi	3.12 de	21.10 bcdefghi
21	Nerica 6	73.85 ghijklm	56.57 fghi	6.65 nopq	2.79 c	2.44 i	20.36 efghijkl
12	Gninni Zeba 33420	73.62 hijklm	58.82 efg	5.68 w	2.88 b	1.97 l	20.60 cdefghijk
10	Gninni Zeba 33423	73.57 ijklm	57.40 efgh	5.69 w	2.92 b	1.94 l	19.83 hijkl
26	CYPRESS	73.42 ijklmn	68.20 ab	7.28 efg	2.22 mn	3.27 bc	19.10 lmnop
9	ITA 123-33433	73.40 ijklmn	51.65 k	6.62 opq	2.48 ghi	2.66 h	19.16 klmno
8	Gnokou Gnokou	73.32 ijklmno	57.77 efg	5.84 v	2.94 b	1.98 l	20.76 cdefghij
20	Hollandais	73.10 klmnop	52.05 ijk	7.14 fghi	2.19 no	3.25 bc	17.76 pqr
1	Danane	73.02 klmnop	61.5 cdef	6.93 kl	2.09 p	3.31 b	16.90 r
14	ITA 123-33434	72.82 klmnopq	52.75 hijk	6.58 pq	2.46 hi	2.67 h	20.00 ghijkl
22	Digbobli	72.52 lmnopq	54.25 ghijk	7.20 efgh	2.46 ghi	2.91 g	20.00 ghijkl
5	Minmli	72.47 lmnopqr	61.57 cde	7.30 ef	2.33 jkl	3.12 de	20.73 cdefghij
23	Jasmine 85	72.35 mnopqr	50.65 k	7.17 fghi	2.29 lm	3.12 de	13.76 t
27	Dawn	71.37 nopqr	61.2 def	7.49 cd	2.11 op	3.54 a	18.16 nopqr
4	BG 90-2-33390	71.32 opqr	61.40 cdef	6.35 st	2.34 jkl	2.70 h	14.93 st
28	SABR	71.22 pqr	67.95 ab	6.75 mno	2.11 op	3.19 cd	17.83 opqr
24	Moluba Kole-33459	70.95 qr	55.02 ghijk	6.90 klm	2.33 kl	2.96 fg	18.33 mnopq
3	BG 90-2-33392	70.92 qr	58.87 efg	6.36 rst	2.33 kl	2.72 h	15.40 s
30	SABR (BMT)	70.75 r	67.52 ab	6.80 lmn	2.13 op	3.18 cd	17.43 qr

Means with the same letter within the same column are not statistically different.

Table 2. Means of the heading and starch properties of the cultivars introduced from West Africa and USA checks grown in Beaumont

No	Varieties	Heading	AA	SA	IA	ASV
1	DANANE	125.0	22.6	13.7	8.9	4.1
2	LOGNINI COURT	124.0	23.4	15.3	8.0	4
3	BG 90-2 -33392	121.7	24.5	12.1	12.4	7
4	BG 90-2 -33390	120.3	24.0	12.0	12.0	7
5	MINMLI	110.3	22.0	12.9	9.0	3.7
6	MOLUBA KOLE-33460	107.0	21.8	13.5	8.3	3.5
7	JAYA	107.0	24.0	10.7	13.3	7
8	GNOKOU –GNOKOU	105.0	22.5	14.0	8.4	3.2
9	IITA 33433	103.3	25.2	14.8	10.4	6
10	GNINNI ZEBA-33423	101.7	22.5	13.7	8.7	3.6
11	YABLO	101.7	22.4	13.6	8.7	3.9

LSD= least significant difference; AA= Apparent amylose; SA= Soluble amylose; IA=Insoluble amylose; ASV=Alkali value

Table 2. Continued

No	Varieties	Heading	AA	SA	IA	ASV
12	GNINNI ZEBA-33420	101.7	22.3	14.0	8.2	3.7
13	GNANLE-GNAN MAN - 33417	101.0	20.7	13.0	7.7	3.7
14	IITA 123-33434	99.0	25.0	15.3	9.7	5
15	MOKOSSI	98.0	22.0	12.6	8.3	3.4
16	MAHAFIN	98.0	21.3	12.7	8.6	3.9
17	BAKUE DANANE	97.0	19.8	11.3	8.6	3.8
18	COCOTE	97.0	21.0	11.9	9.0	4.2
19	WAB 638-1	97.0	20.4	11.1	9.2	4.1
20	HOLLANDAIS	95.7	22.4	13.9	8.4	3.8
21	NERICA 6	95.7	22.1	13.9	8.2	4.1
22	DIGBOBLI	95.0	21.8	13.4	8.3	4.7
23	JASMINE 85	93.0	15.2	9.0	6.2	6.1
24	MOLUBA KOLE-33459	91.7	22.6	13.7	8.9	4.6
25	GNANLE-GNAN MAN - 33416	87.0	21.6	12.5	9.0	3.9
26	CYPRESS	83.3	21.0	11.9	9.0	3.8
27	DAWN	82.7	22.0	13.7	8.2	3.5
28	SABR	82.0	19.7	10.3	9.3	3.9
29	SIERRA	82.0	25.3	15.7	9.7	4
30	SABR(BMT)	82.0	20.0	10.0	10.0	3.6
31	CHENIERE	82.0	25.3	16.3	8.9	3.9
32	BENGAL	79.0	10.6	5.6	4.9	6
33	COCODRIE	79.0	25.1	16.1	8.9	3.1
34	NERICA 7	77.7	21.0	12.4	8.6	3.3
35	NERICA 1	77.7	25.3	15.0	10.2	3.6
36	NERICA 4	76.3	20.0	10.8	9.2	3.2
37	NERICA 3	75.7	20.3	10.8	9.4	3.2
38	WAB 56-104	73.0	20.6	11.3	9.2	3.9
39	NERICA 2	72.3	25	14.9	10.0	4
40	NERICA 5	71.3	24.3	14.3	10.0	3.7
41	BALDO	70.7	13.0	6.4	6.6	5
42	ZHE733	64.7	23.6	11.8	11.8	3.4
43	ZHE733(BMT)	64.7	23.6	11.9	11.6	3.1
	LSD 5%	4.11	0.81	0.88	1.03	0.54

LSD= least significant difference; AA= Apparent amylose; SA= Soluble amylose; IA=Insoluble amylose; ASV=Alkali value

Table 2. Continued

No	Varieties	Protein	Peak	Hot	Bkdn	Cool	Stbk	CSV
1	DANANE	6.6	302.90	161.1	141.8	294.7	-8.1	133.6
2	LOGNINI COURT	5.8	283.73	135.6	148.1	258.6	-25.1	123.0
3	BG 90-2 -33392	8.4	287.3	197.3	90.0	392.1	104.8	194.8
4	BG 90-2 -33390	8.6	285.0	206.6	78.4	387.6	102.7	181.0
5	MINMLI	8.4	266.2	163.0	103.2	299.3	33.1	136.2

LSD= Least significant difference

Table 2. Continued

No	Varieties	Protein	Peak	Hot	Bkdn	Cool	Stbk	CSV
6	MOLUBA KOLE-33460	7.4	275.0	146.9	128.0	280.4	5.4	133.5
7	JAYA	9.0	369.1	285.7	83.4	460.0	90.0	174.3
8	GNOKOU –GNOKOU	7.1	288.8	149.3	139.5	277.6	-11.2	128.3
9	IITA 33433	8.5	243.4	159.3	83.8	313.5	70.1	154.0
10	GNINNI ZEBA-33423	6.4	299.5	158.1	141.3	285.0	-14.5	126.8
11	YABLO	7.2	290.1	143.7	146.4	278.23	-12.0	135.5
12	GNINNI ZEBA-33420	6.5	300.7	150.0	150.6	275.43	-25.2	125.3
13	GNANLE-GNAN MAN -33417	7.2	293.3	136.6	156.7	262.2	-31.1	125.7
14	IITA 123-33434	8.8	241.1	150.2	91.4	307.8	66.2	157.6
15	MOKOSSI	7.3	287.9	153.2	134.7	290.4	2.5	137.2
16	MAHAFIN	6.9	301.6	148.3	153.3	283.7	-17.9	135.3
17	BAKUE DANANE	8.3	301.2	160.6	140.6	317.5	16.2	156.9
18	COCOTE	7.6	318.6	171.4	147.2	320.7	2.1	149.3
19	WAB 638-1	8.6	290.8	158.9	131.8	311.3	20.5	152.3
20	HOLLANDAIS	6.8	301.5	151.8	149.6	299.6	-1.9	147.7
21	NERICA 6	7.2	286.2	162.9	123.3	305.0	18.7	142.0
22	DIGBOBLI	7.1	302.2	159.8	142.3	300.2	-1.9	140.4
23	JASMINE 85	8.2	327.4	138.6	188.8	244.1	-83.3	105.4
24	MOLUBA KOLE-33459	6.8	290.3	151.1	139.1	288.0	-2.2	136.9
25	GNANLE-GNAN MAN -33416	7.3	299.4	143.5	156.0	276.3	-23.1	132.8
26	CYPRESS	8.1	292.0	146.3	145.8	284.8	-7.2	138.6
27	DAWN	7.2	297.1	148.7	148.5	281.8	-15.4	133.1
28	SABR	8.0	290.9	169.8	121.0	314.8	23.9	145.0
29	SIERRA	7.4	307.4	197.2	110.2	377.0	69.6	179.8
30	SABR (BMT)	7.7	295.4	165.0	130.4	307.6	12.1	142.6
31	CHENIERE	9.1	182.9	101.4	81.5	221.0	38.0	119.5
32	BENGAL	8.7	319.0	158.0	161.0	238.7	-80.3	80.7
33	COCODRIE	7.6	230.1	145.7	84.4	297.1	67.0	151.4
34	NERICA 7	8.4	297.1	154.5	142.6	276.1	-21.0	121.6
35	NERICA 1	7.8	267.7	158.4	109.3	311.8	44.2	153.5
36	NERICA 4	8.4	299.2	144.5	154.7	274.1	-25.1	129.6
37	NERICA 3	8.3	293.9	147.4	146.5	271.0	-22.9	123.6
38	WAB 56-104	8.2	299.9	159.7	140.2	285.6	-14.3	125.9
39	NERICA 2	9.0	269.5	147.8	94.7	327.9	58.4	153.0
40	NERICA 5	8.9	269.7	153.2	116.5	295.8	26.1	142.6
41	BALDO	8.0	333.5	183.8	149.7	282.9	-50.5	99.1
42	ZHE733	8.8	321.3	219.7	101.7	383.4	62.0	163.7
43	ZHE733 (BMT)	9.0	302.5	194.6	107.8	358.83	56.3	164.2
	LSD 5%	0.68	24.54	19.71	18.80	26.07	19.54	11.7

LSD= Least significant difference

UPGMA cluster analysis (Figure 1) of the physico-chemical data based on the Pearson coefficient grouped the accessions into eight major clusters at a coefficient of 0.99. The first cluster comprised 21 varieties, the second cluster seven, the third group two (Bengal and Jasmine), and the fourth group only one variety (Baldo). The fifth group contained five varieties, the sixth group five, the seventh group one variety (Cheniere) and the eighth group one variety (Jaya). Jaya had a unique characteristic not similar to any USA material. Most of the

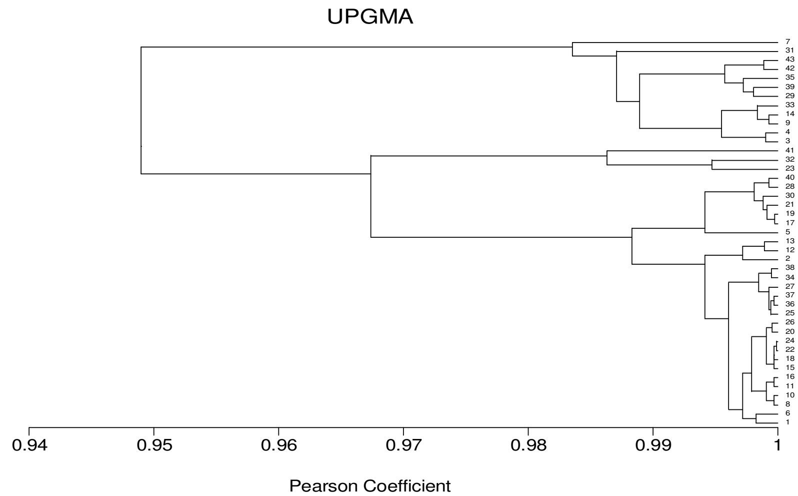

Figure 1. Dendrogram (UPGMA) constructed based on the heading and the cooking caracteristics the African varieties and the USA checks grown in Beaumont

Table 3. Means of the aroma content of selected aromatic parents from West Africa. And USA checks

Varieties	Aroma (2-AP ng/g)
Sierra	1258.83 a
Bakue Danane	1140.00 ab
Cocote	1102.00 ab
WAB 638-1	1075.33 b
Jasmine 125	494.00 c
Nerica 1	444.00 c

Means with the same letter within the same column are not statistically different.

landraces from Côte d'Ivoire fell within the first group where we have Dawn from the USA. Dawn is not an improved variety *per se* and does not have good agronomic traits, but it has good grain quality. NERICA 1 was in the same group as Sierra known for its aroma. Saber is in the same group as NERICA 5, NERICA 6, WAB 638-1 and Bakue Danane, a traditional variety from Côte d'Ivoire.

Aroma Characteristics of the West African Cultivars Grown in Beaumont

The results showed that Sierra, a USA check, had the highest value of 2-AP (1258 ng g^{-1}) (Table 3). It was followed by Bakue Danane and Cocote, both from Côte d'Ivoire in WA. Jasmine 85, a check from the USA, and NERICA 1, an interspecific variety, were not statistically different, with 494 and 444 ng g^{-1} of 2-AP, respectively.

Experiment 2. Mbé-Bouaké/Côte d'Ivoire

Physico-Chemical Analyses of Milled Samples Introduced from Africa Rice Center

Chemical Analysis Results

Apparent amylose content varied from 15% for Khao Dawk Mali 105, which originated from Thailand, to 26% for CG 14, an *O. glaberrima* type from WA (Table 2) and ITA 123, an improved *O, sativa* from WA.

The traditional variety Doigamlin, which had an apparent amylose content of 25%, had a minimum cook-

Table 4. Grain cooking parameters of 39 African accessions produced at Africa Rice Center and milled samples sent and analyzed in Beaumont.

No	West African Accessions	Amylose Content %	Cooking Time Min	ASV 1.5% KOH	ASV 1.7% KOH	Rapid Visco Analyzer Peak	Hot	Cool	Bkdn	Stbk	Init.T	DSC Onset	Delta H	Peak	End
1	BAKUE DANANE	21.1	19.5	3.9	4.7	226	158	334	67	109	87	70	2.99	75	80
2	BASMATI 217	21.0	15.7	4.3	5.3	156	140	276	16	120	92	70	3.23	74	80
3	BASMATI 370	22.8	13.5	4.0	4.8	191	145	298	46	107	87	69	3.06	74	79
4	BASMATI 6129	21.4	14.0	3.9	4.7	202	161	320	41	117	89	70	3.05	74	80
5	BG 90-2(FARO 29)(GR 14)(ROK 28)	24.7	15.0	7.0	7.0	214	156	341	58	127	81	61	1.63	66	70
6	BIEU	24.6	15.5	4.0	5.0	335	196	376	139	41	78	68	2.77	73	79
7	CG 14	26.1	18.5	3.5	5.0	196	170	277	26	81	86	71	3.16	75	80
8	COCOTE	22.8	15.8	3.9	4.6	237	174	355	63	118	88	70	3.20	75	81
9	DANANE	23.3	17.0	3.6	4.7	304	176	337	128	33	80	70	3.16	75	83
10	DIGBOBLI	22.9	19.5	3.3	4.7	284	182	344	102	60	81	71	3.29	75	81
11	DISSOU	22.6	19.0	4.0	5.0	222	162	334	60	112	87	69	3.01	74	80
12	DOIGAMLIN	25.2	13.0	3.9	5.2	283	158	354	124	72	81	71	2.88	74	78
13	GAMBIAKA KOKOUN (MALI)	24.7	17.6	4.0	5.0	175	160	318	15	144	88	71	3.08	75	80
14	GNANLE GNAN-MAN	22.7	19.0	2.8	4.8	258	147	315	111	56	84	72	3.39	75	80
15	GNINNI ZEBA	23.0	19.7	3.3	4.8	242	156	304	86	62	85	70	2.98	75	82
16	GNOKOU GNOKOU	23.1	19.7	2.6	4.3	237	147	297	90	60	85	70	2.99	75	81
17	HOLLANDAIS	24.2	15.7	3.4	5.0	230	161	333	69	103	86	70	4.21	75	81
18	ITA 123 (FKR 28) (TOM1-3)(KADIAKA)	26.0	20.0	6.2	6.3	233	195	365	38	132	86	64	0.58	69	72
19	JAYA	25.6	17.0	7.0	7.0	363	267	486	96	123	75	62	2.44	67	72
20	KHAO DAWK MALI 105	15.0	11.9	6.0	6.8	237	171	333	66	97	89	64	2.87	68	74
21	LOGNINI COURT	23.3	20.8	3.8	4.0	254	162	317	92	63	83	70	3.13	75	81
22	MAHAFIN	22.6	19.0	3.0	4.8	277	168	327	108	50	82	70	3.17	75	81
23	MELKIN BARBA	25.8	20.0	4.0	5.1	280	176	396	104	116	78	70	3.25	74	79
24	MINMLI	22.8	20.0	3.8	4.0	234	151	306	83	72	85	72	2.88	75	80
25	MOKOSSI	22.8	20.8	2.3	4.4	259	152	318	107	59	83	71	2.57	76	82
26	MOLOUBA KOLE	22.5	18.0	3.8	4.8	264	175	328	89	65	83	69	2.91	75	80
27	PA LAHAI (KAOLAKA)	24.8	20.0	3.0	4.0	308	202	380	106	72	81	72	3.33	76	81
28	PUSA BASMATI	24.2	11.7	6.3	7.0	258	240	419	19	160	89	64	2.29	68	76
29	SUPER BASMATI	21.5	13.0	4.2	5.7	188	159	307	28	119	90	70	2.77	75	82
30	WAB 450-11-1-1-P31-HB (NERICA 5)	24.7	20.6	3.1	4.8	139	108	207	31	68	83	72	2.71	76	82
31	WAB 450-11-1-P-31-1-HB (NERICA 2)	23.6	20.7	3.3	4.3	170	127	256	43	86	83	58	2.83	75	82
32	WAB 450-I-B-P-160-HB (NERICA 6)	23.5	20.0	4.0	5.8	183	140	288	43	105	88	70	3.03	73	80
33	WAB 450-I-B-P-20-HB (NERICA 7)	22.2	23.0	3.9	5.2	211	145	282	65	71	85	70	2.77	74	82
34	WAB 450-I-B-P-28-HB (NERICA 3)	21.7	20.8	3.2	4.5	211	143	294	68	84	85	71	3.02	75	80
35	WAB 450-I-B-P-38-HB (NERICA 1)	25.3	20.0	4.0	4.0	239	172	332	67	92	80	71	2.90	75	81
36	WAB 450-I-B-P-91-HB (NERICA 4)	22.6	21.0	3.8	4.3	228	142	295	86	67	81	70	2.85	74	80
37	WAB 56-104	21.1	24.0	3.4	4.8	154	128	259	27	105	89	70	3.10	76	83
38	WAB 638-1	20.8	20.7	2.8	4.0	193	158	328	35	135	90	72	2.82	77	82
39	YABLO	23.6	19.0	3.7	4.6	250	147	305	103	56	82	69	2.21	75	81

ASV= Alaki spreading value

Table 5. Means of the different variables from cultivars produced in two different locations: West Africa (WA) and Beaumont (BMT).

Parameters	WA	BMT	Sdt Err. WA	Stdt Err.BMT
AA	23.2	22.3	1.32	1.60
ASV	3.8	4.1	1.17	0.97
Peak	234.3	292.1	46.43	22.23
Hot	159.2	160.4	28.80	28.38
Cool	317.4	302.8	48.20	41.14
Bkdn	75	130.7	27.64	22.90
Stbk	83.0	10.1	28.65	36.86
CT	19.5	19.8	2.08	1.95

Table 6. Paired comparisons between the West African and USA environments for the different variables.

Parameters	Mean Diff	Sdt Error	T Value	Pr>t
AA	0.88	0.15	5.85	<0.0001
ASV	0.30	0.11	2.79	0.0099
Peak	57.80	7.62	7.59	<0.0001
Hot	1.21	4.13	0.29	0.7705
Cool	14.55	7.24	2.01	0.0554
Bkdn	55.52	5.50	10.09	<0.0001
Stbk	72.89	5.61	12.98	<0.0001
CT	0.29	0.29	0.99	0.3304

ing time of 13 minutes. Other cultivars from WA having less than 16 minutes cooking time were BG 90-2, Bieu, Hollandais, Cocote, Danane, Jaya, and Gambiaka Kokoun. In contrast, WAB 56-104, an improved variety from Africa Rice Center, had the longest cooking time of 24 minutes (Table 2).

The results suggest that the 1.5% concentration gave more accurate measurements for the samples grown in WA. At this concentration, ASV showed the widest range and was more highly correlated (r = -0.93) with gelatinization temperature as measured by the peak DSC value than at the 1.7% concentration (r = -0.80, data not shown).

The RVA Peak values varied from 139 for NERICA 5, an interspecific cultivar from WA, to 362 RVU for Jaya, a Taiwanese cultivar that is well adapted to the irrigated system in the Sahel in WA. Both of these cultivars have similar amylose contents but widely differing RVA curves.

Comparative Study of Important Cooking Characteristics of Milled Samples of Cultivars Grown in both West Africa and Beaumont, USA

AA, ASV, Hot, Cool and CT were not strongly affected by the environment (Tables 5 and 6) when WA samples grown in Côte d'Ivoire were compared with those grown in Texas. The variable most affected by environment was the Stbk which predicts the hardness of the cooked rice. The same cultivars produced in Beaumont (BMT) were softer than when they were produced in WA environment.

DISCUSSION

The high amylose level of 26% for CG 14 is an indicator that *O. glaberrima* is a genetic resource of genes that will affect cooking and eating properties in rice (Aluko et al. 2004). The results showed that African cultivars possessed the full range of amylose content classes although no waxy classes (0% amylose) were found among them. High amylose types of rice with superior processing qualities are indicated for canning purposes as stated by (Beachel and Stansel 1963) and (USDA 2000) in the USA. They cited Newrex, Rexmont, Dixiebelle and L 205. Therefore, varieties such as NERICA 1, ITA 123, BG 90-2 and Lognini Court could be good sources for USA rice improvement programs.

High RVA peak values and high apparent amylose content are indicators of good parboiling and canning stability. Thus, Jaya can be compared to Dixiebelle, a USA variety grown commercially under contract for the canning and processing industries. The demand for rice of superior quality is becoming a priority for rice breeding programs worldwide (Juliano 1990) and the divergent RVA curves of NERICA 5 and Jaya indicate that the WA germplasm may have grain chemistry traits.

Milling yield depends on many factors, including grain shape, grain moisture, the depth of surface grooves and the pressure required to remove the bran (Bhashyan and Srinivas 1984; Juliano and Perez 1993). Gnanle Gnan-Man, a landrace from Côte d'Ivoire, had 78% of total milling. It can be a good source for greater milling, comparable to Cypress and Cocodrie (Gravois et al. 1991). NERICA 3, NERICA 4, and WAB 638-1 are good sources for grain characteristics in the USA.

Imported aromatic rice represents 9.5% of total USA rice consumption (USDA, 2000). They are mainly from Thailand (80%) (e.g. Jasmine); India and Pakistan (e.g. Basmati) . There is a need for sources of aroma in the USA. Bakue Danane, and Cocote (landraces from WA) and WAB 638-1 (an improved type from WA) (MINAGRA 1998) are good sources for aroma, in addition to the US check Sierra.

The lack of environmental effect for most of the cooking parameters is somewhat surprising, considering the difference in latitude, soil types, weather patterns, and management practices between the USA and WA. This suggests that cereal quality results from WA are predictive of their performance in Texas. Chen and Zhu (1999) studied the genetic effects and genotype x environment interactions for cooking quality traits in *Indica-Japonica* crosses. They concluded that the expression of dominant genes is affected by environmental factors without changing their directions. The results from the UPGMA showed that WA introductions were diverse in their characteristics and therefore can be used as parents or direct uses in the USA breeding programs. Many of the cultivars from WA were described for the first time and they are good sources for grain quality both for WA and the USA.

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