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Technological, physicochemical and culinary characterization of African rice accessions (*Oryza glaberrima*)

Claude GNACADJA[1,2,3*], Balbine FAGLA AMOUSSOU[2], Baboucar MANNEH[5], Seth GRAHAM-ACQUAAH[3], Florentin AMETONOU[5], Saïdou SALL[6], Paulin AZOKPOTA[1,2] and Moussa SIE[4]

[1] Laboratory of Molecular Biology and Food Formulation; Nutrition, Food and Technologies Sciences School, Faculty of Agricultural Sciences, Abomey Calavi University, Benin.

[2] Laboratory of Food Sciences; Nutrition, Food and Technologies Sciences School, Faculty of Agricultural Sciences, Abomey Calavi University, Benin.

[3] Africa Rice Center (AfricaRice), Cotonou, Bénin.

[4] Africa Rice Center (AfricaRice), Madagascar.

[5] Africa Rice Center (AfricaRice), Senegal.

[6] Training and Research Unit in Agricultural Sciences, Aquaculture and Food Technologies, GASTON BERGER University, Saint-Louis, Senegal.

[*] Corresponding author; E-mail: gnacaclaude@yahoo.fr; Tel:+229 96426871.

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ABSTRACT

Thanks to its contribution to human nutrition, rice is a vital issue, mainly based on its quality. While *O. glaberrima* is abandoned in favor of Asian rice, this study was carried out in identification process of best grain quality of African rice, in order to make them more competitive and valorous in systems of varietal improvement. Principal components analysis method has been used for characterization of 215 African rice accessions, based on their technological, physicochemical and cooking parameters. The results showed on average a high amylose content (28.82%), a cooking time of 20.20 min, machining yield of 62.71% and score of 5 for gelatinization. Three clusters have been identified. Essentially, Cluster 1 is specifically characterized by a low chalkiness (10.29%), cluster 2 is characterized by a low broken rate (25%) and good machining yield (64%) while the cluster 3 of accessions is characterized by high index of « Volume expansion » and « water uptake » during cooking. These accessions represent a solution approach to meet the different requirements in terms of improving varieties integrating nutritional properties and food processing for the development of African rice.

Keywords: *O. glaberrima*, milling, cooking test, amylose, gelatinization.

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INTRODUCTION

Rice (Oryza *Spp)* is the main nutritional resources for about 50% of the world's population with a global consumption of 54.3 kg per person per year (FAO, 2017). First cereal cultivated for human consumption, rice is a vital and commercial issue for many African countries. Its commercial character is much more based on its quality. Indeed, the commercial quality is mainly determined by the physical properties and the name of the variety. The machining degree, the color and the age of milled rice are also indicators of grain quality (Gnacadja et al., 2017). The cooking and consumption quality is determined by the physicochemical properties, in particular, the apparent amylose content (a constituent of starch which represents major part of the milled rice), the viscosity and some other properties (Demont et al., 2013; Ibrahima et al., 2019). On the basis of these species, the introduction of Asian varieties and the development of interspecific varieties contributed to the regression of African rice cultivation. Yet it has been used for a long time for the development of improved varieties whose success does not fully satisfy the ambitions of breeders and the expectations of producers and consumers. Producer's preferences are often oriented towards a better rice quality and every country or region prefers rice with a particular range of "grain-quality" traits that can be linked to culinary, physicochemical or technological properties (Calingacion et al., 2014). This study aimed at identifying the best varieties of African rice, based on technological, physicochemical and cooking quality for their use in breeding systems and valorization of the species. These results will also improve and diversify rice-based food products.

MATERIALS AND METHODS

Experimental site

The work was done in the « Grain Quality » Laboratory of Africa Rice Center (Africa Rice) at Cotonou.

Material

The material consists of 215 samples (validated accessions *O. glaberrima*) characterized in agronomy (Gnacadja et al., 2018) and 2 controls (CG 14 NERICA4). All 215 accessions come from irrigated ecology at Sahel AfricaRice. They were planted in august 2016 and harvested in December 2016.

Study parameters

The samples were processed in augmented design in randomized complete block device with a coding of their identifier for the reliability of the data. The following parameters have been studied.

Determination of technological parameters for machining

Moisture before milling was measured with a moisture meter (Single Xemel Moisture Tester PQ-510) which displays on its screen the value of humidity of the sample and the corresponding deviation standard.

Machining efficiency and Broken rice rate were determined by the following method: (i) dehusking of 150 g of paddy in a Satake dehusker huller (THU 35B, Satake, Tokyo, Japan); (ii) polishing in a single-pass friction rice pearler (BS08A, Satake). iii) whole grains were separated from the broken in Satake Test rice Grader TRG 058. The byproducts after each operation are weighed to determine machining efficiency and broken rice rate for each sample.

The samples were milled into flour with a UDY cyclone mill (Fort Collins, CO, U.S.A.) fitted with a sieve of 0.5 mm mesh size.

Determination of physicochemical parameters

S21 test (chalkiness and dimensions) was measured on 50 g of whole rice in "Rice Statics Analyzer" (S21 LKL Technologia), fitted with a camera, and connected to a computer which displays and automatically calculates the average value of chalkiness and the grain size. The thickness of the grains was estimated by the ratio of the length to the width (L / 1).

Alkaline Spread Value (ASV-test) was determined using the method described by Little and al. (1958). 10 ml of KOH (1.7%) solution prepared and stored for at least 24 hours were poured on 6 grains rice (whole and milled) placed in dishes which were then incubated at 30°C for 23 hours. Samples were observed after incubation and a score was assigned to each sample according to its spreading level.

Apparent Amylose Content (AAC) of the rice flour was determined with Auto-Analyzer (SEAL Analytical XY 2) in duplicate following AACC International Approved Method 61-03.01. (Juliano et al., 1981; William and al., 1958).

Determination of culinary parameters

Cooking time, volume expansion and water uptake were determined following WARDA method (WARDA, 2004).

Statistical analysis

A database has been generating with the test repetitions averages. A descriptive analysis was made with R software commands. Then, Principal Component Analysis (PCA), Hierarchical Ascending Classification (HAC) and variance analysis were the grouping methods. The values-test obtained were used to sort the variables that characterize the clusters.

RESULTS

The descriptive results data are presented in Table 1. They show for each variable studied, the minimum and maximum values on the one hand and on the other the means and standard ecotypes.

This table 1 reveals for this collection studied, a high amylose content (28.82 %), a mean cooking time of 20.20 min, an average machining efficiency of 62.71% and an average score of 5 for gelatinization.

The hierarchical classification represented by this dendrogram (Figure 1) reveals that three large groups (clusters) emerge.

The accessions of the clusters, generally have a similarity for the variables studied (Figure 2).

Table 2 shows the different values-tests for the variables of each cluster. This table reveals that for cluster 1, broken rate, cooking time, apparent amylose content and chalkiness have the highest absolute values-tests (> 3). However, the highest absolute values-tests are observed in cluster 2 for cooking parameters, apparent amylose content and broken rice. As for cluster 3, water uptake, volume expansion and broken rate that are most remarkable. These distinguishing variables characterize the different clusters.

It appeared from this classification that cluster 1 consists of 90 accessions of which the CG14 control, cluster 2 includes 99 accessions with the control NERICA4 and cluster 3 includes 27 accessions.

Table 1: Descriptive results of technological, physicochemical and culinary parameters.

Variables	Average	Min*	Max**	StdDev***
Moisture	11.91	10.05	14.01	0.37
Machining Efficiency (%)	62.71	34,13	69.50	3.13
Broken rate (%)	35.65	13.76	80.10	12.31
Long (mm)	6.14	5.56	6.83	0.14
Width (mm)	2.42	1.93	2.74	0.08
Long / Width	2.51	2.88	3.15	0.26
Chalkiness (%)	12.86	4.14	38.76	5.57
Cooking time (min)	20.20	17.33	23.25	0.91
Volume Expansion	2.90	2.31	3.62	0.17
Water uptake (g)	1.57	1.03	2.15	0.14
ASV	5.19	3.58	7	0.56
AAC (%)	28.82	13.15	35.28	3.06

*=Minimum ; **=Maximum, ***=Standard Deviation
ASV=Alkaline Spread Value ; AAC= Apparent Amylose Content

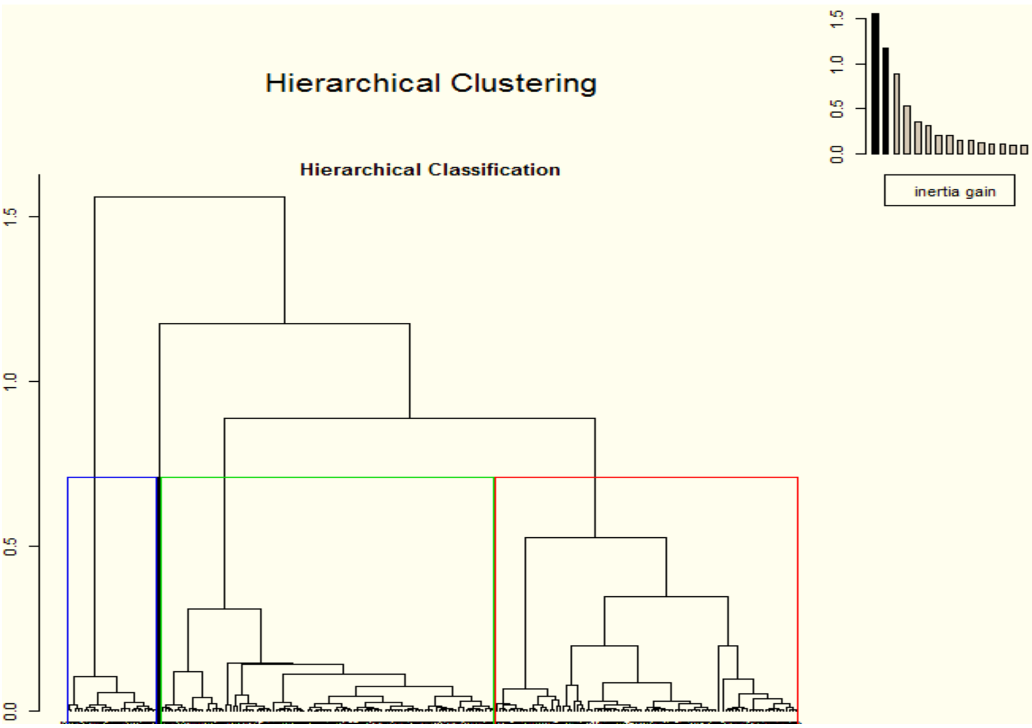

Figure 1: Hierarchical classification based on technological, physicochemical and culinary parameters

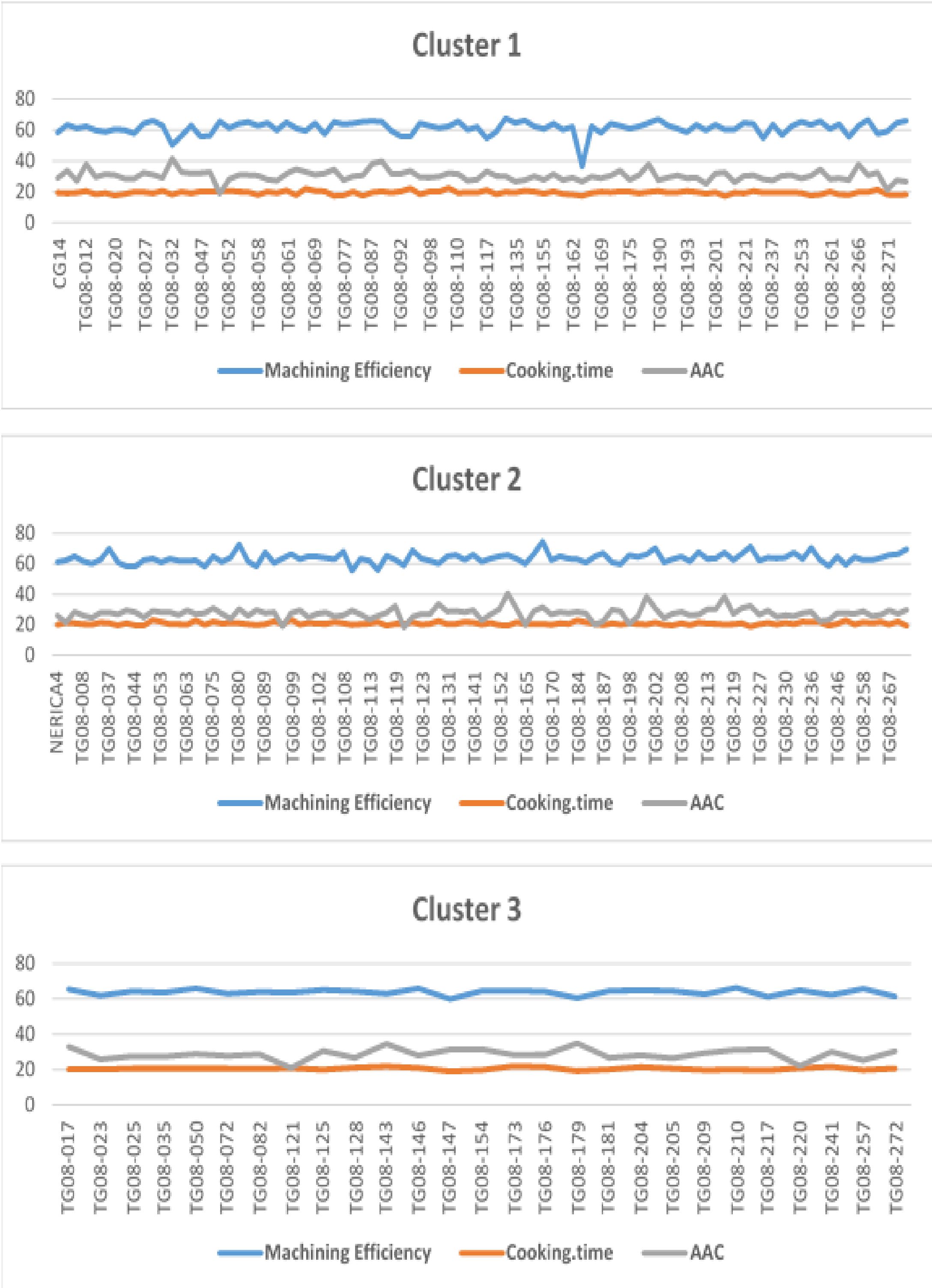

Figure 2: Distribution of *O. glaberrima* Accessions in Clusters (1, 2 and 3) population based on Machining Efficiency, Cooking time and Apparent Amylose Content.

Table 2: Values-tests (according to clusters) of technological, physicochemical and culinary parameters.

Variables	Values-test		
	Cluster 1	**Cluster 2**	**Cluster 3**
Moisture	-2.65	/	3.19
Machining Efficiency	-3.95	3.13	/
Broken rate	9.36	-6.41	-4.36
Long	/	/	/
Width	/	/	/
Long / Width	2.64	/	/
Chalkiness	-4.58	2.40	3.04
Cooking time	-7.50	6.43	/
Volume Expansion	-3.47	-4.46	12.27
Water uptake	-3.34	-4.45	11.97
ASV	/	/	/
AAC	5.27	-5.07	/

ASV=Alkaline Spread Value ; AAC= Apparent Amylose Content

DISCUSSION

Technological parameters for machining, physicochemical and culinary properties

The relatively low average moisture content obtained in the collection has impacted the technological properties of the grains. This relatively dried appearance of paddy has affected the milling efficiency, resulting in a relatively high broken rate in the collection. Moisture below 12% have been reported to cause the cleavage of grain during dehusking and to increase not only the broken rate, but also the loss in flour (WARDA, 2004). For this samples without impurity, machining efficiency of 62% could be explained by the losses related to fragility of paddy relatively dried. It was reported that the fragile grains break easily during dehusking, leading to a high broken rate and flour losses (Sarla and Swamy, 2005; Nayar, 2010). Indeed, optimal machining efficiency have been indicated between 67 and 70 % (WARDA, 2004). In addition, machining efficiency has influenced by the rates of dehusking and milling byproducts. These factors (milling yield, broken rate) are determined by the properties of paddy (moisture, maturity etc.) and the technique of machining (Bergman et al., 2004). Studies have shown that agricultural practices can influence the characteristics of rice grain (Zossou et al., 2021). Indeed, the conditions of the agronomic test from which the samples come is a wintering climate (August - December) in Sahelian environment with a remarkable temperature drop in December have been accompanied by the cold weather through which the plants have sustained. Repeating the same agronomic test, will allow us to study correlation between climate and moisture, and to confirm the impact of ripening temperature on grain moisture.

The ratio length / width (grain thickness index) which varies between 2.88 and 3.15 mm explains a shorter and more or less rounded appearance of the grains. These are parameters that provide information on the suitability of the grains that will be used for parboiling.

Ratios of around 3 have been reported by Osaretin et al. (2007) for traditional rice varieties in Nigeria. Ray (2005) has shown in his work that long and flat paddy, generally are better suited for parboiling. Other authors have also reported that the dimensions of grain provide a better index for quality and cooking ability (Gayin, 2015). Indeed, for varieties of Asian species, it has been reported that elongated and less thick grains are desirable criteria for rice quality (Hossain et al., 2009). Other authors have reported that the optimum cooking time of rice cooked in excess water is dependent on the thickness and surface of the grain (Debabandya and Bal, 2005). This relationship between thickness and cooking time could be due to the rapid diffusion of humidity into thin grains. Round grains have a low specific surface area compared to long, fine grains; that suggests that the thickness and surface of the grain are important determinants of water diffusion during cooking (Debabandya and Bal, 2005).

Chalkiness made it possible to appreciate the translucency of the grains that present for this parameter a variability. Indeed, if a part or whole milled rice is opaque, it is chalky. Although it disappears during cooking, and does not affect the appearance of rice, it negatively affects the quality of milled rice (IRRI, 2012). For this purpose, Xian-Zhong and Bruce (2001) had reported that the non-glutinous rice containing a relatively high proportion of amylose and amylopectin, has a translucent albumen, while glutinous rice having a low proportion of amylose and a high rate of amylopectin, has an opaque albumen due to the presence of pores between the starch granules and within them.

Culinary tests were used to evaluate the ability of rice for cooking. The cooking time for example depends on several parameters, in particular the physicochemical properties. The degree of milling affects the moisture-absorbing ability and determines the optimum cooking time of the rice. Indeed, Mohapatra and Bal (2006) reported a decrease of cooking time for grains with a high degree of whitening. The results of this study are in accordance with those obtained by Gayin (2015) who reported during his study on *O. glaberrima* varieties, the cooking times between 16 and 23 min with averages of 19 min for varieties IRGC103 759 and IRGC8674 and 20 min for TOG12440. In addition, for *O. sativa* varieties cultivated in Africa, average cooking times of 20.8 min have been also reported by Danbaba and al. (2011). The results of this study, however, disagree with those obtained by Oyegbayo et al. (2001) who has reported cooking times between 52 and 56 minutes for two local varieties of rice. These differences could be explained not only by the genetic characteristics of the different materials used (rice varieties), but also by the chalky or non-chalky aspects of these materials.

« Volume expansion » and « water uptake » are parameters that expressing the cooking abilities of the grains. Indeed, thickness, surface of gains and amylose content are important factors influencing water uptake during cooking (Debabandya and Bal, 2005). « Volume expansion » varies between 2.31 and 3.62 in this study and are in accordance with the results obtained by Gayin (2015) for *O. glaberrima* varieties whose values range between 2.38 and 3.50.

The chemical properties as alkaline test and apparent amylose content made it possible to better appreciate the previous results, because gelatinization temperature and amylose determine also the culinary characteristics. The average score of alkaline spread (5) indicate an intermediate alkaline digestibility of the grains with gelatinization temperatures ranging from 70 to 74°C. At this temperature, the swelling of the grains leads to the pasting phenomenon. Gelatinization is a hydrothermal process corresponding to irreversible swelling and to the solubilization of starch granules and giving to the rice a typical gelatinized appearance of the starch (Parker and Ring, 2001). For these same authors, the temperature of gelatinization is the temperature at which the starch granules irreversibly lose their crystalline order during cooking. The values obtained in this study are slightly below those obtained for *O. glaberrima* varieties by Gayin (2015) who reported average values between 75 and 76°C for gelatinization temperature.

Compared to the amylose content, it is an apparent content because the rice samples have not been dilapidated before the analysis tests. The average apparent rate of 28.82% with a maximum value of 35.28 % in the collection of this study, are results slightly above those obtained by Gayin (2015) who reported an average of 26.2%. The differences could be related to the genetic characteristics of the accessions studied. These results show that accessions can generally be classified as being of superior quality in amylose content. In fact, levels higher than 25% in amylose characterize high grade contents (Cruz and Khush, 2000). The apparent amylose content is an important factor which determine the quality of rice and serves as a link between several properties of cooked rice. This important power of amylose also allowed us to understand the variations within the collection. Regardless of amylose content, the culinary quality of rice may also be influenced by components such as: proteins, lipids or amylopectin (Cai et al., 2011).

Regarding the dimensions, it has been reported (without precision of specie) that cooking and eating qualities of rice are mostly determined by amylose content, gel consistency and gelatinisation temperature of the grain endosperm. The appearance quality is determined by grain shape, as specified by length-width ratio and the translucency of the endosperm (Tan et al., 2000; Kitara et al.,2019). Other authors have also noted that rice varieties with a high gelatinization temperature are resistant to water uptake (Yogesh et al., 2014). Otherwise, the variabilities about « Volume expansion » and « water uptake » could be attributed to differences of amylose content (Sodhi and Singh, 2003). In fact, the degree of cooking of rice is influenced by the gelatinization temperature of the starch granules (Bao, 2012). By studying five types of starches isolated from cereal cultivars (gray millet, creamy white millet, wheat, rice and maize), Ghada et al. (2017) revealed that cereal starches are significantly different in their amylose content, thus showing that the Amylose content of starch varies depending on the botanical source of the starch.

Classification and characteristic of clusters

The multivariate analysis made it possible to classify the accessions into three groups from a projection on the first two axes of the PCA. This analysis has shown that the fundamental difference between the accessions is related to the variables that define the axes expressing the essential information of the collection. This grouping showed that cluster 1 consists of 90 accessions, while the clusters 2 and 3 includes respectively 99 and 27 accessions. The values-test (v-test) obtained made it possible to distinguish the variables that strongly characterize the population of each cluster. So, we retain that:

The accessions grouped in cluster 1 are specifically characterized by:

- a higher ***apparent amylose content*** than the average of the studied collection
- a relatively low ***cooking time*** compared to the average of the collection
- a ***chalkiness*** relatively low compared to the average of the population studied.

Cluster 2 accessions are specifically characterized by:

- a ***broken rate*** relatively low than the average of the collection,
- the ***« Volume expansion » and « water uptake »*** of grains relatively below the average of the collection studied.

Accessions of cluster 3 are specifically characterized by:

- a low ***broken rate*** compared to the average observed in the collection
- the ***« Volume expansion » and « water uptake »*** more important than the averages of the studied collection.

Conclusion

Processing technology applied to rice provides several products derived. Transformation techniques involve physicochemical, culinary and rheological properties depending on the products desired by the consumer. This study identified three main groups: accessions with high amylose content and low cooking time constitute the first group; those characterized by a good machining efficiency constitute the second group, while the third group of accessions is characterized by high index of « Volume expansion » and « water uptake » during cooking. These results are useful for technological applications and can also help in advanced selection integrating grain quality aspects for the development of varieties that meet the aspirations and tastes of the consumer. In addition, rice is appreciated on the basis of several parameters (amylose being the important parameter) defining the criteria of quality and choice for consumers. This hierarchical classification study that note the importance of relationship between apparent amylose and other characteristics related to « grain quality » is a solution approach to meet the various requirements for dietary treatments desired by consumers and transformers. In perspective, a correlation study can be conducted to establish the link between the physical and chemical properties and agronomic characteristics of accessions.

COMPETING INTERESTS

There is no conflict of interest for the publication of this article.

AUTHORS' CONTRIBUTIONS

CG: main author who carried out the activities; BFA: Supervisor of activities with the main author (technical and scientific contribution in food biochemistry); BM: supervisor at AfricaRice (proofreader and correction); SG-A: Assistant who supervised the work at the AfricaRice grain quality laboratory; FA: Biostastician who supervised data management and analysis; SS: Supervisor of the main author and coordinator of the HAAGRIM project (reviewer and scientific contribution); PA: Thesis director of main author and general work supervisor (proofreading and scientific contribution); MS: Thesis co-supervisor and supervisor at AfricaRice.

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