Effect of parboiling and storage on grain physical and cooking characteristics of the some NERICA rice varieties

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Abstract
Four upland NERICA varieties (NERICA 1, 2, 4 and 6), all of which have been officially released or adopted in Benin, and an *O. sativa* check variety (WAB 638-1) were used to access the interactive effects of parboiling and storage on the grain quality. Milling characteristics (husking yield, total milling return and head rice yield), grain hardness, chalkiness, cooking time, and volume expansion ratio were compared among samples stored for 6, 13, 26, 39 and 64 weeks. The samples were stored in a room, under ambient conditions (average room temperature of 27°C and relative humidity of 43%). Interaction between storage duration and parboiling process had significant (P<0.05) effect on all parameters studied except the chalkiness and milling yield regardless of variety. For most of the quality traits measured, no consistent changes were observed in parboiled samples' parameters during storage. Unparboiled samples needed 23 to 39 weeks of storage to have similar physico-chemical properties to parboiled samples. However, a sharp reduction of the gap between the two treatments was observed for almost all parameters studied from 6 to 39 weeks of storage. Between 39 and 64 weeks, higher values were recorded with unparboiled than parboiled samples for all the NERICA varieties for all measured parameters. For the improvement of physical and cooking characteristics, such as hardness, husking yield, head rice ratio, volume expansion, tenderness and softness upon cooking, parboiling process should be recommended for saving time.

Introduction
Parboiling results in significant changes in the physico-chemical and cooking characteristics of rice grain. Parboiling fills the void spaces and cements the cracks inside the endosperm, making the grain harder and minimizing internal fissuring and thereby breakage during milling (Correa *et al.*, 2006). The market value of milled rice as a product depends largely on its physical qualities after the processing. The percentage of whole grain is the most important parameter in the rice processing industry (Marchezan, 1991). Broken grain has half the market value of head rice, which is defined as grains between 75 and 100% the length of whole kernels. Storage of rice grains is a crucial stage in the processing of paddy rice for consumption. The duration of the storage period depends on the objectives of the producers and marketers. Storage is also a necessity in the seed production system. Extensive research has been carried out on the optimum conditions required, the nature of storage structures, and the nature and extent of changes that occur during the storage of rice (Pillaiyar, 1988). Some properties of the rice grain are related to the duration and conditions of storage. Kongkiattikajorn *et al.* (2004) report that peak viscosity of rice stored at 25°C increased throughout storage. However, when stored at 37°C, the peak viscosity increased in the first month but decreased subsequently. Changes in rice properties, including viscosity, color, flavor and composition, affect rice quality (Suzuki *et al.*, 1999). Hull (1955) reports that under normal storage conditions grains exhibit continuous physico-chemical changes due to the physiological activities of the germ and endosperm, and these affect culinary properties and nutritive value. Knowledge of the changes in physico-chemical and cooking characteristics of agricultural products is of fundamental importance for correct storage and processing, as well as for the design, fabrication and operation of equipment used in the post-harvest processing of these products (Afonso, 2001). Very little scientific information is available on the interactive effects of the parboiling process and storage on the physico-chemical and cooking characteristics of rice. The objective of this work was to determine the effect of storage and parboiling on rice grain quality and interactive effect of the two treatments on the grain quality traits of some popular cultivars in West Africa.

Materials and methods
Four upland NERICA varieties (NERICA 1, 2, 4, 6), all of which have been officially released or adopted in Benin, along with *O. sativa* check variety WAB 638-1 (*indica* type) were grown on-station at Africa Rice Center (Cotonou) and took an average of 120 days to mature. WAB638-1 was used because it is widely grown in West Africa and especially in Benin for its good agronomic and superior grain quality traits.

Drying process
Paddy samples from each variety were shade-dried until the moisture content stabilized at about 14%. Grain moisture content was measured using a Riceter J301 (KETT, Japan).

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Parboiling equipment
The parboiling equipment consisted of a paddy-holding vat and a moulded aluminum pot. The paddy-holding vat is perforated at the bottom and tightly fits on top of the aluminum pot which contains water (Fig. 1).

Figure 1. Improved parboiling equipment used for the study: (A) general shape of the improved parboiler; (B) the steaming vat.

Storage method and parboiling process
Sufficient quantity of well-dried seed (about 14% moisture content) of each variety was kept in a cotton bag in a room (average 27°C and 43% relative humidity). At each sampling date, a 500 g sample of paddy rice of each variety was parboiled in the laboratory. Samples were soaked in 1L of warm water in a well-closed saucepan (volume 5 L) for 24 hours. After soaking, the samples were removed from the water, drained and spread on a cotton bag for 16 h (overnight) in a laboratory (average 27°C) without humidity control (average 43%). Samples were then steamed until the hulls split. Steamed paddy was spread on a cotton bag and dried under laboratory ambient conditions until their moisture content stabilized at about 14%.

Milling characteristics
Husking yield (HY), milling yield (MY) and head rice ratio (HRR) — the ratio of brown rice to paddy, milled rice to brown rice, and head rice to milled rice, respectively — were determined on weight basis. For each NERICA variety, the 250 g of winnowed paddy was hulled with a testing husker (THU 35H, Satake Engineering Co. Ltd, Japan). Brown rice was weighed and HY determined. Then 150 g of brown rice was The brown rice obtained was whitened in a single-pass friction rice pearler (BS08A, Satake Engineering Co. Ltd, Japan) with the degree of whiteness set between 'Low' and 'Medium' on the equipment. After milling, rice bran was removed with a 1.7 mm sieve. A cleaned sample of milled rice was weighed and the MY determined. From 20 g of cleaned milled rice, all head rice was taken and weighed. HRR was then calculated. Milled rice grains with a length greater than three-quarters of that of complete grains were considered as head rice. Colored and damaged grains were also removed from the category of head rice.

Grain hardness
Grain hardness was measured using a Kiya grain hardness tester (Fujihara Seisakusho LDT, Japan). For each rice sample, 10 grains were tested. A grain of rice was placed on the platform of the hardness tester. The handle of the hardness tester was turned until the probe touched the grain. The handle was further turned till grain cracked under pressure. At this time, the black pointer returns to the zero point and the 'mother pointer' (red) remains. The reading of the 'mother pointer' (kg) indicates the hardness of the grain. This measurement was carried out in triplicate.

Chalkiness
Two hundred whole grains were selected randomly and visually assessed for chalkiness. A score of 1 (less than 10% chalkiness), 5 (10 to 20% chalkiness) or 9 (over 20% chalkiness) was given to each sample according to the standard evaluation systems of the International Rice Research Institute (IRRI, 2009). This determination was carried out in triplicate.

Whiteness and translucency
The whiteness and translucency of the milled rice were determined using a milling meter (MM-1B, Satake Engineering Co. Ltd, Japan). The milling meter was calibrated using the 'standard white and brown plates'. The sample case was filled with grains and placed in the sample inlet port.

The values of whiteness and translucency displayed on the screen were recorded. This measurement was carried out in triplicate.

Gel consistency
The gel consistency of the samples was determined using the method of Cagampang *et al.* (1973).

Cooking time
Five grams of milled rice of each sample (in triplicate) was taken and poured into 135 ml of vigorously boiling distilled water in a 400 ml beaker and covered with a watch glass. After 10 min boiling, 10 grains were removed every 1 minute with a perforated ladle. The 10 grains were pressed between two petri dishes. The grains were considered cooked when at least 9 out of the 10 grains no longer had opaque centers and the time recorded.

Swelling ratio
Eight grams of milled rice were put in a wire mesh cooking basket (in triplicate). The average length of the raw rice (H1) was measured with a vernier caliper. The weight of the cooking basket plus raw rice (W1) was measured. The cooking basket was lowered into 160 ml boiling water in a 400 ml beaker with the intensity of the hot plate set to 'high'. After 1 minute, the intensity was turned to 'low' and the beaker covered with a watch glass. Samples were then cooked for the time determined by the cooking tests above and the basket was removed and drained. The weight of the cooked rice and cooking basket (W2) and the length of the cooked rice (H2) were recorded.

Swelling ratio = H2/H1

Water uptake ratio = (W2–W1)/8

Data analysis
The data obtained were analyzed using analysis of variance (ANOVA) (program SAS 11.0) at a 95% confidence level. The graphs and Hierarchical cluster were made using SPSS 16.0. The percentage of increase or decrease of the studied parameters was calculated using the value of the 6 weeks of storage of each treatment as 100%.

Results and discussion
The interactive effects of storage and parboiling were significant for all the studied parameters except the milling yield and the chalkiness (Table 1). Hardness is the most important physical property of parboiled rice, as it reduces breakage during milling, which significantly increases market value and consumer acceptability. It is generally understood that cooked parboiled rice is harder and less sticky than cooked raw rice (Islam *et al.*, 2001). In this study, the hardness increased for both parboiled and unparboiled samples between 6 and 39 weeks of storage for all studied varieties except for NERICA 1, hardness value of which dipped at week 26 (Fig. 2). The increase was sharper for unparboiled samples. Most of the unparboiled samples needed at least 39 weeks to reach the mean hardness values (level) of parboiled rice samples stored for 6 weeks (Fig. 2).

Table 1. Significance of the interaction between storage duration and parboiling process

Variable	Degrees of freedom	Mean square	F	Significance
Hardness	4	60.93	129.43	0.000 ***
Husking yield	4	211.64	38.85	0.000 ***
Milling yield	4	13.56	1.32	0.266 ns
Head rice	4	172.14	63.92	0.000 ***
Whiteness	4	5.94	3.85	0.006 ***
Translucency	4	0.20	3.11	0.019 ***
Cooking time	4	24.95	8.10	0.000 ***
Volume expansion	4	4.41	67.57	0.000 ***
Gel consistency	4	956.80	61.46	0.000 ***

*** Significant at 1% level.
ns = not significant.

Similar trends of changes were found for husking yield, milling yield and head rice ratio of each variety studied. For unparboiled samples, the highest increase in husking yield was recorded with WAB638-1 (23.04%), followed by NERICA 2 (20.23%); the highest increase in head rice ratio was found with NERICA 2 (19.95%). With the parboiled rice samples, the highest increases in the husking yield (15.52%) and head rice ratio (3.48%) were recorded with WAB638-1. The effectiveness of parboiling paddy in improving the quality of milled rice is well known (Bhattacharya and Subba Rao, 1966b; Marshall *et al.*, 1993). Parnsakhorn and Noomhorm (2008) state that increase in head rice yield after parboiling process is observed because of increased tensile strength of

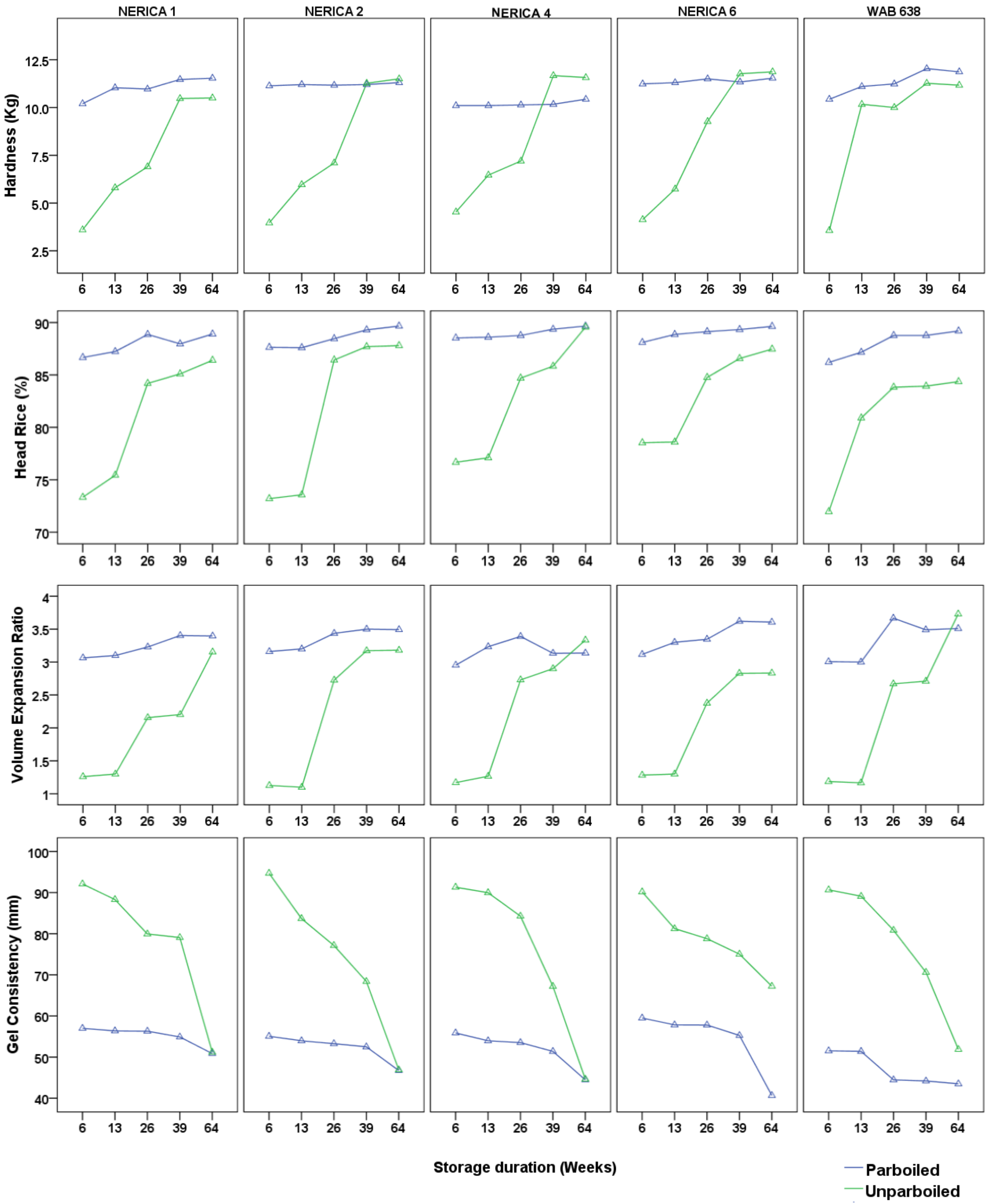

Figure 2. Physical and cooking quality traits changing trends in parboiled and parboiled rice.

the kernel caused by gelatinization of the starch granules, so that the kernel tolerates milling and suffers reduced grain breakage.

Although the cooking time increased with the storage duration, for storage duration up to 39 weeks the cooking time was longer for parboiled samples than for unparboiled samples (Fig. 3a). A consistent increase in cooking time was observed after 26 weeks of storage. At 64 weeks, the relationship switched from longer cooking time for parboiled to shorter cooking time for parboiled (except for NERICA 1) (Fig. 3a). These findings roughly show that cooking time depended on several factors, including the parboiling process, storage duration and variety, as previously described Hogan (1963). The increase in volume expansion (Fig. 2) followed similar trend to that of cooking time (Fig. 3a). However, the increases of the volume expansion were significantly between 13 and 26 weeks of storage (Fig. 2).

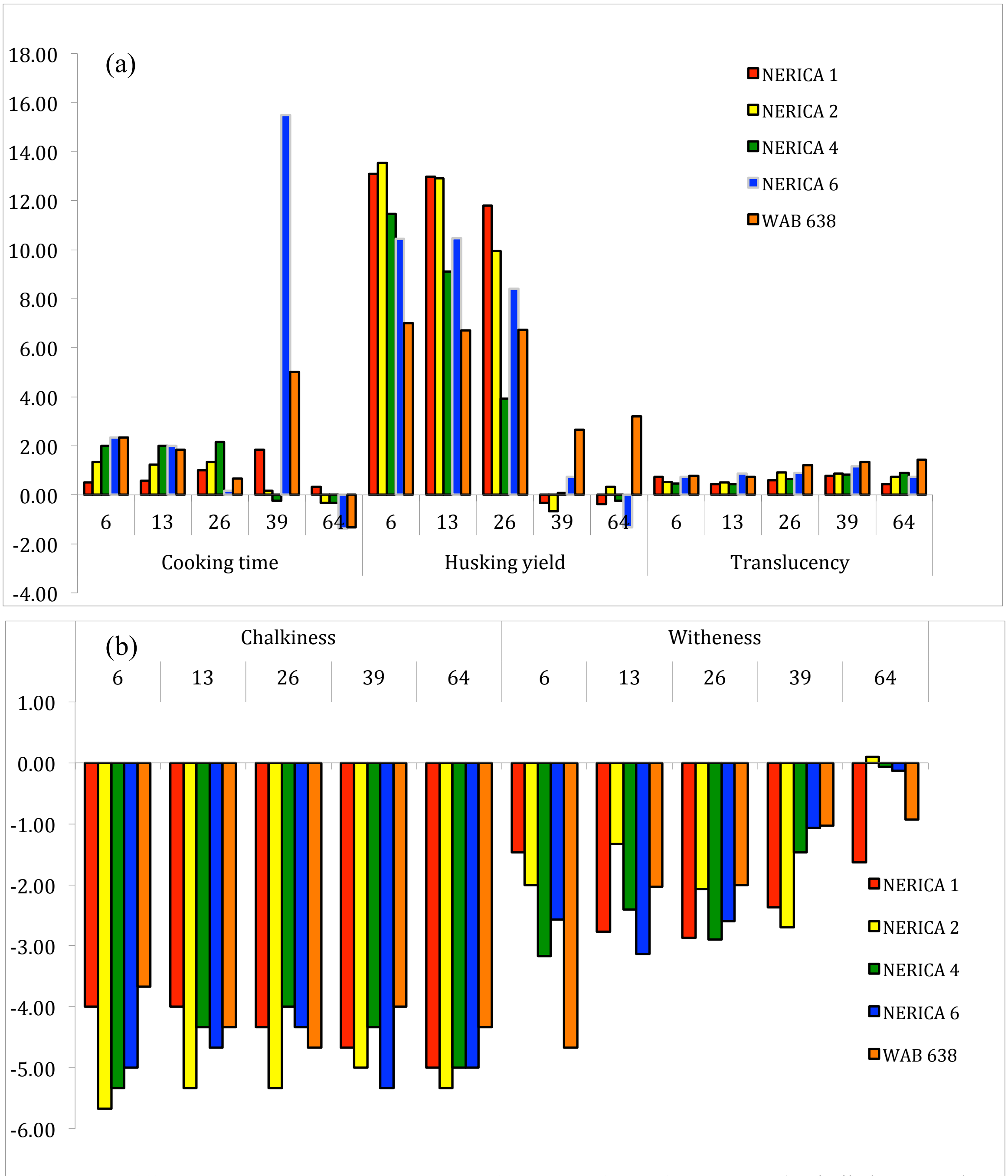

Figure 3. Differences between the mean value of each quality trait recorded (parboiled mean value – unparboiled mean value of parboiled value).

Gel consistency is known to influence the tenderness of cooked rice (Cagampang *et al.*, 1973). A high value of gel consistency indicates soft texture and lower values of gel consistency indicate harder texture. Gel consistency was higher in unparboiled samples than in parboiled samples at all storage durations except at 64 weeks for NERICA 1, 2 and NERICA 4. In both parboiled and unparboiled samples, gel consistency decreased from 6 weeks to 64 weeks of storage.

Though chalkiness disappears upon cooking and has no direct effect on cooking and eating qualities such as taste or aroma, excessive chalkiness downgrades the quality and reduces milling recovery (Islam *et al.*, 2001).

Grain appearance is largely determined by the endosperm opacity and this is commonly classified as the amount of chalkiness. The chalky appearance is associated with the development of numerous air spaces between loosely packed starch granules and the resulting change in light refraction (Tashiro and Wardlaw, 1991). A major cause of chalkiness is considered to be exposure to high temperatures during the ripening period (Tashiro and Wardlaw, 1991). In this study, no clear trend was observed with the changes in the chalkiness at different storage durations; however, the results clearly showed that parboiling drastically reduced the chalkiness meaning that ageing had no effect on the chalkiness (Fig. 3b).

Whiteness (Fig. 3b) is another factor that influences the price of parboiled rice and rice stored for too long. Several studies report that the temperature and period of soaking and steaming significantly influence whiteness of parboiled rice (Bhattacharya, 1996; Kimura *et al.*, 1993). The changes in color of brown rice (parboiled or rice stored for too long) are known to be mainly caused by Maillard-type nonenzymatic browning (Bhattacharya and Subba Rao, 196b; Pillaiyar and Mohandas, 1981). The contribution of pigments to coloration of parboiled rice is supported by the fact that some nutrients from the bran compounds leach out during parboiling (Framlingham and Anthony, 1996). The whiteness decreased with the storage duration for both parboiled and unparboiled samples. At all storage durations, the whiteness values were higher in unparboiled samples than in parboiled samples, except for NERICA 2 at 64 weeks. The findings showed that unparboiled samples of rice should be stored at least 39 weeks to have similar whiteness value to parboiled samples stored for 6 or 13 weeks. After 64 weeks of storage, parboiled and unparboiled samples of NERICA 2, 4 and 6 had similar values of whiteness. The whiteness value of WAB 638-1 stabilized after 39 weeks of storage for both unparboiled and parboiled samples; similar changes were observed with parboiled samples of NERICA 1.

The change patterns of studied quality traits during storage and the interactive action of parboiling and storage are combined in Figure 4. The results clearly showed that grain physical and cooking proprieties were different in unparboiled samples and parboiled samples. However, parboiled samples of all NERICA varieties had almost the same behavior although NERICA 2, 4 and 6 were closest. Unparboiled samples fell into three groups: a first group comprising NERICA 1 and NERICA 6, a second group comprising NERICA 2 and NERICA 4, and WAB 638-1 on its own. All the quality traits studied either increased or decreased with the storage duration. However, the parboiling process drastically reduced the time required to reach a given level of reduction or increase.

Conclusion

This study was carried out to assess the changes in physical and cooking characteristics of stored rice samples and to examine the effect of parboiling on these parameters. Findings showed a consistent gap between the values recorded with parboiled and unparboiled samples. This gap was greater in the first weeks of storage, then progressively reduced for all measured parameters; after 39 weeks of storage most of the measured traits were almost equal regardless the treatment (parboiled or unparboiled) except for NERICA 6 and WAB 638). Changes in proprieties in unparboiled samples were faster than those in parboiled samples at all storage durations from 6 to 39 weeks, showing that parboiling process could be a good tool to save time when trying to improve certain physical and cooking quality traits of freshly harvested rice.

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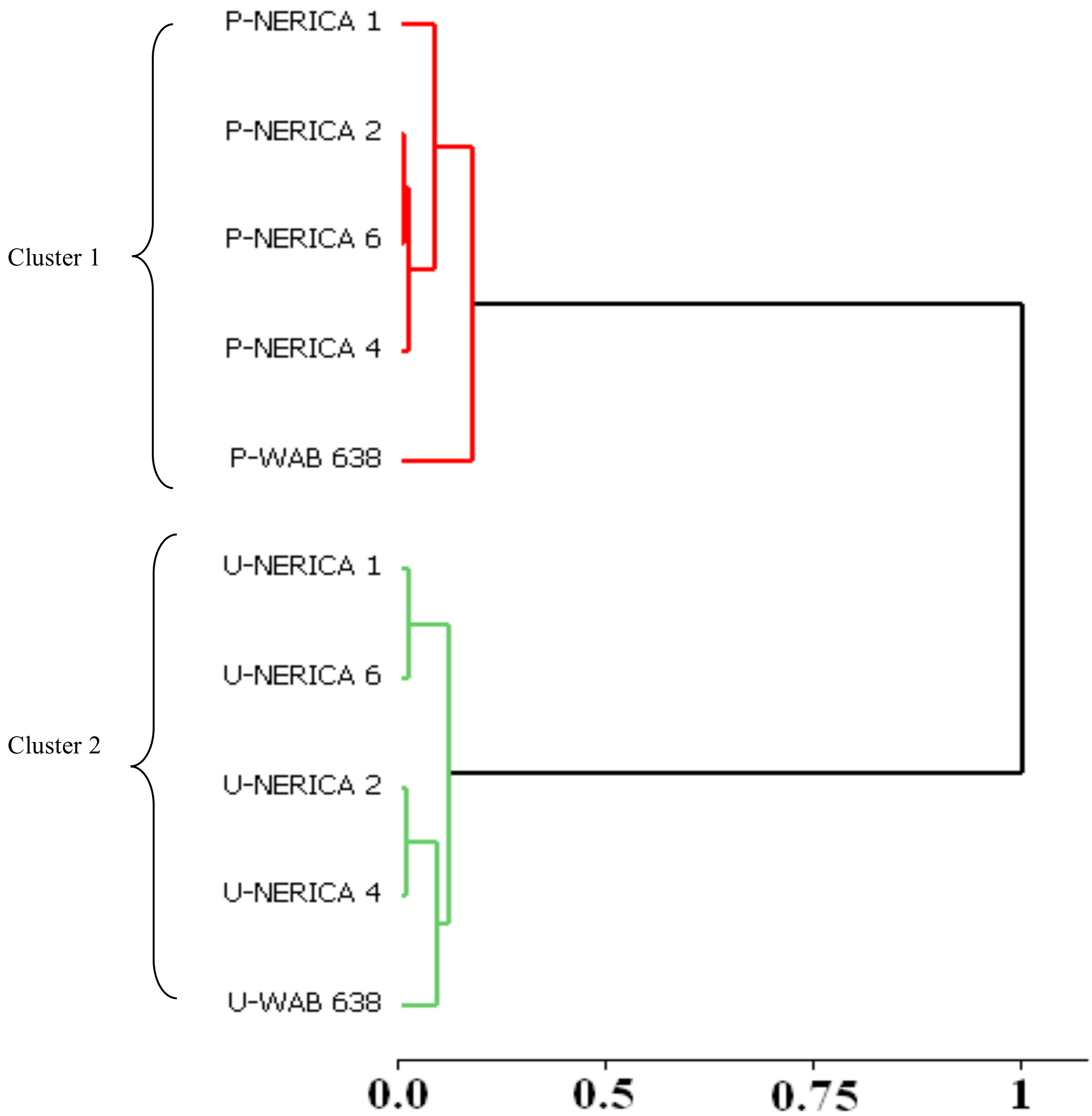

Figure 4. Comparison of studied varieties' behaviors according to the treatments.
U, unparboiled; P, parboiled.

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