Journal of Agricultural Science and Food Technology
Vol. 2 (4), pp. 55-63, May, 2016
ISSN: 2465-7522
Full Length Research Paper
http://pearlresearchjournals.org/journals/jasft/index.html

Effect Of Different Soil Moisture Levels At Reproductive Stage On Rice Grain Quality

Roseline T. M. Bleoussi[1*], Innocent Bokossa Yaou[1], Mamadou Fofana[2], Nestor H. I. Bassole[3], Guy A. Mensah[4], Nébpawinde Kabore[3] and Célestin K. C. Tchekessi[1]

Acceptd 24 April, 2016

[1]Laboratory of Microbiology and Food Technology of University of Abomey-Calavi, 04BP 1107, Cotonou, Benin.
[2]Laboratory of physiology of AfricaRice, Ibadan (AfricaRice).
[3]Laboratory of biochemistry of the University of Ouagadougou, Burkina Faso.
[4]National Agricultural Research Institute of Benin, 01BP884 RecettePrincipale, Cotonou 01, Bénin.

ABSTRACT

Rice grain quality indicators are important in varietal development and subsequent adoption by farmers and consumers. Two experiments were carried out during dry season 2013 in an open field and wet season 2014 in a screen house to assess the effect of four levels of soil moisture content on rice grain quality indicators (Head Rice Ratio, Amylose content, Protein content and Gel consistency) at reproductive stage. Five improved rice varieties (NERICA1, NERICA 4, NERICA 7, ARICA 4 and ARICA 5) were used. Significant changes (P< 0.05) in grain quality traits due to changes in soil moisture content were found. Head rice ratio, grain amylose content and gel consistency decreased with increasing drought intensity. The lowest values of head rice ratio 42 to 44% were recorded with ARICA varieties under severe water deficit condition. The mean reduction ingrain amylose content was 36% for NERICAs and 31% for ARICAs. Higher reduction ingel consistency was found with NERICA varieties (11%) thanARICA varieties (9%). Protein content for each variety increased when drought intensity increased. The highest value (11.65%) was observed with NERICA 7 under severe water deficit conditions.These results show that soil water deficit has significant implications on rice grain quality.

Key words: Arica, Nerica, Grain quality, Reproductive stage and Water deficit.

*Corresponding author. E-mail: bleoussiroseline@hotmail.fr. Tel. +22994032617.

INTRODUCTION

Rice consumption is growing faster than that of any other food commodity in Africa, because it has become a convenience food for the growing urban populations (Futakuchi et al., 2013). Imports of rice (close to 10 million tons (Mt) per year) cost to the African continent more than US$5 billion in 2009 (Manful, 2011; Seck et al., 2012). There is an urgent need to substitute imported rice with locally produced rice. Locally produced rice is often not competitive as compared to imported rice because of their perceived lower quality (Fofana et al., 2011; Futakuchi et al., 2013). Consumers' acceptability for rice grain quality may vary from one country or region to another (Fofana et al., 2010a). In Nigeria, consumers dislike locally produced rice compared to imported rice mostly because of the impurities like stones and other innert matters which it contains (Tiamiyu et al., 2011). Rice with low grain breakage is preferred in most countries, but broken rice is liked in Senegal (Futakuchi et al., 2013). Red rice is sold at a higher price than white rice in Kumasi (the second largest city in Ghana), but this is not true for other markets in Ghana (Sakurai et al., 2006). Grain quality has different meanings to various operatives in the rice value chain as well: farmers, processors, millers, nutritionists, policy-makers, marketers, purchasers and consumers (Manful, 2011).

Environmental stress can disrupt cellular structures and impair key physiological functions. Drought (Deficit of water to plants during growth or/and reproductive stage) and other abiotic stress such as salinity, and low temperature stress impose an osmotic stress that can lead to turgor loss. As a major component of plant tissue, areagent for chemical reactions and a solvent for translocation of metabolites and minerals as well as an essential factor for cell enlargement through increasing turgor pressure, soilwater availability greatly influences rice grain quality (Fofana et al., 2010b; Pandey et al., 2014). Soil moisture deficit affects physiological processes such as photosynthesis and translocation of assimilates from their main sources (leaves) to their main sinks (plant tissues). It affects rice plant growth and causes poor grain filling which leads to incidence of chalkiness and a high proportion of broken grains/low Head Rice Ration during milling (Samonte et al., 2001).

In the context of current unpredictable water availability exacerbated by the worldwide instability of rainfall pattern due to climate change, water deficit may occur at any stage during the growth of rice plants and cause enormous losses in terms of grain yield especially when this deficit occurs during the reproductive stage (Ndjiondjop et al., 2012). Africa Rice's scientists have made great progress in developing upland rice varieties with different ranges of drought stress tolerance (Ndjiondjop et al., 2010). Many research works have been carried out focusing on the effect of water deficit on riceproduction (Mostajeran and Rahimi-Eichi, 2009; Sokoto and Muhammad, 2014), but few of them have included the impact of this abiotic stress on rice grain quality. This study was carried out to determine the effects of four levels of soil moisture content during the reproductive stage of rice plants on some key rice grain quality indicators such as head rice ratio, protein content, amylose content, gel consistency.

MATERIALS AND METHODS

Plant Materials

Three upland NERICAs (New Rice for Africa): NERICA 1, NERICA 4 and NERICA 7 and two ARICA (Advanced Rice for Africa): ARICA 4 and 5 were used. Both generations of rice varieties were developed by Africa Rice. All the selected rice varieties are well adapted to upland ecology and widely adopted by farmers in Sub-Saharan Africa (SSA). NERICA 1, NERICA 4, NERICA 7 and ARICA 4 were developed by interspecific hybridization between two cultivated species of rice - *O. sativa* (Asian rice) and *O. glaberrima* (African rice). ARICA 5 was developed from a three ways cross between ITA 257, IDSA 6 and ROK 16.

Experiments Location

During the dry season of 2013 (DS2014), an open field trial was conducted at Ikenne in the sub-station of the International Institute of Tropical Agriculture (IITA). Ikenne is at 6°52'N latitude, 3°43'E longitude of about 70 m above mean sea level and within the rainforest ecology of Nigeria. During the wet season of 2014 (WS2014), a screen house trials was conducted at the International Institute of Tropical Agriculture (IITA), Ibadan, Oyo state, Nigeria, situated at latitude $7^0$30'8''N and longitude $3^0$54'37''E about 273 m above sea level. Grain quality analyses were carried out in both Biochemical and plant biology, ecology laboratories of the University of Ouagadougou, Burkina Faso, West Africa.

Experimental Design

The experiments were laid out in split plot design with three (3) replications. In the open field, land was ploughed and harrowed using a machine. In the screen house, soil was dug (20 cm depth) and then filled with Ikenne soil. Soil sampled from Ikenne was spread in the screen house such as to maintain in situ soil bulk density (1.4 $g.cm^{-3}$BD) as in Ikenne. The bulk density of the soil in the screen house was carefully monitored when compacting using a Static Cone Penetrometers (model HM-559A, Gilson company, INC. Ohio, USA). In each experiment, seeds were hand-dibbled; four seeds were sown at adepth of about 2 cm at a spacing of 20 cm × 20 cm. Seedling were thinned to two plants per hill. The single plot size measured 3 m x 2 m = $6m^2$ in open field and 0.8 m x 2 m = 1.6 m^2 in screen house; single plot were separated by 0.5 m while sub-plots were separated by 5 m. Water was supplied through sprinkler irrigation from seeding to the beginning of the stress (7 weeks after planting). Two rows of border plants were maintained in all the trials. Fertilizer was applied as follows; NPK fertilizer was applied at the rate of 50-50-50 $kg.ha^{-1}$(as basal treatment) at 10 days after sowing (DAS). Top dressing urea was done at 30 and 40DAS at the rate of 40 kg $N.ha^{-1}$. In the open field, the whole experimental field was surrounded by wire net to prevent rice plants against rats and other rodents. From flowering to harvesting, the field was covered by a bird-net to avoidany reduction of grain due to bird damages. Each plot was maintained weed free by periodic hand weeding.

Water Management And Soil Moisture Monitoring

Before the beginning of the stress period, each plot was well watered (soil moisture close to the field capacity) using overhead sprinkler irrigation in both sites. During the stress, water was supplied using watering can in the screen house while sprinkler irrigation was used in open field. Soil water status was monitored using tensiometers Irrometer (Model ''R'' 30 cm, IRROMETER COMPANY, Riverside California) installed at 30 cm soil depth in each plot. In each experiment, four levels of water regimes were used as treatments:

* L0: In the first treatment, plots were maintained at the

soil moisture content close to field capacity throughout the experiment (Tensiometer readings were maintained within0 to -5Kpa throughout the trial);
* L1:Low stress intensity; plots were maintained at tensiometers readings fluctuated between -30 to -40Kpa from 49 days (7 weeks) after planting until harvesting;
* L2: Moderate stress in which water supply was withdrawn until harvesting and the soil moisture maintained between -50 and -60Kpa;
* L3: Severe water stress in which tensiometers readings were maintained between-70 and -85Kpa from 7 weeks after planting to harvesting.

Data Collection

Soil Component and Environmental Data

Before planting, soil samples (0 – 20 cm depth) from Ikenne were collected and analyzed in IITA Soil Science Laboratory to determine their properties. Environmental data were collected using a weather station (Model WS-GP1 of Delta-T devices Ltd, 130 Low Road, Burwell Cambridge, CB25 OEJ, UK) installed near the field (15 meters) at Ikenne.

Harvesting, Drying and Threshing

At maturity, panicles were harvested with knives. Harvested panicles were bundled and shade dried before threshing. In each sample, unfilled grains and other foreign matter such as dead insects, leaves and sticks were removed from the samples.

Grain Moisture Content

Each sample was shade dried until its moisture content reach 14%. During the process, grain moisture was monitored usinga moisture tester Kett Riceter (KETT C600). The tray of the moisture tester was filled with paddy samples (10 grains) and the knob was turned until the moisture reading is displayed.

Determination of Head Rice Ratio (HRR)

For each variety, 200 g of winnowed paddy was hulled with a Satake testing husker (THU 35H). One hundred grams (100 g) of brown rice was milled with a milling machine for laboratory use (Yamamoto Test Rice Whitener VP-31T). After milling, rice bran was removed with 1.7 mm sieve. Twenty grams (20 g) of cleaned sample were weighed, all head rice were separated to broken grains and weighed. HRR was then calculated. Milled rice grains with a length greater than three-quarters of complete grains were considered as head rice. Colored and damaged grains were also removed from the category of head rice.

Amylose Content

The procedure used to determine amylose content in this study is a modification of a Con A method developed by Yun and Matheson (1990). It uses an ethanol pre-treatment step to remove lipids prior to analysis. In this study, 0.02 g of rice powder was completely dispersed by heating in dimethyl sulphoxide (DMSO). Lipids were removed by precipitating the starch in ethanol and recovering the precipitated starch. After dissolution of the precipitated sample in an acetate/salt solution, amylopectin was specifically precipitated by the addition of Con A and removed by centrifugation. The amylose, in an aliquot of the supernatant, was enzymically hydrolyzed to D-glucose, which was analyzed using glucose oxidase/peroxidase reagent. The total starch, in a separate aliquot of the acetate/salt solution, was similarly hydrolyzed to D-glucose and measured calorimetrically by glucose oxidase/peroxidase. The concentration of amylose in the starch sample was estimated as the ratio of Glucose Determination Reagent (GOPOD Reagent) absorbance at 510 nm of the supernatant of the Con A precipitated sample to that of the total starch sample.

Protein Content

Protein content of the sample was determined using Kjeldahl method. It consists of heating 0.2 g of the powder of each sample with sulphuric acid which decomposes the organic substance by oxidation to liberate the reduced nitrogen as ammonium sulphate. In this step potassium sulphate was added to increase the boiling point of the medium. Chemical decomposition of the sample was complete when the initially very dark-colored medium becomes clear (colourless). The solution was then distilled with a small quantity of sodium hydroxide, which converts the ammonium salt to ammonia. The amount of ammonia present, and thus the amount of nitrogen present in the sample, was determined by back titration. The end of the condenser was dipped into a solution of boric acid. The ammonia reacts with the acid and the remainder of the acid was then titrated with a sodium carbonate solution by way of a methyl orangepH indicator.

Gel Consistency

Gel consistency was determined according to Cagampang et al. (1973). For each sample, 100 mg of rice powder flour was placed into a glass test tubes, 0.2 ml of thymol blue in ethanol solution was added followed by shaking and 2.0 ml of 0.2N KOH addition. The mixture was then boiled in a water bath followed by cooling in ice cold water. The tubes were then kept horizontally on a millimeter paper and the length of the gel was measured from the bottom of the test tube after 45 min.

Table 1. Mean of air temperature, air humidity, wind speed, solar radiation and rainfall during the experiments periods.

Weather parameters	DS2014	WS2014
Air temperature (degC)	27.9	25.4
Humidity (%)	86.2	93.1
Wind speed ($m.s^{-1}$)	1.3	0.6
Radiation ($w.m^{-2}$)	174	121
Rainfall (mm)	0.08	59

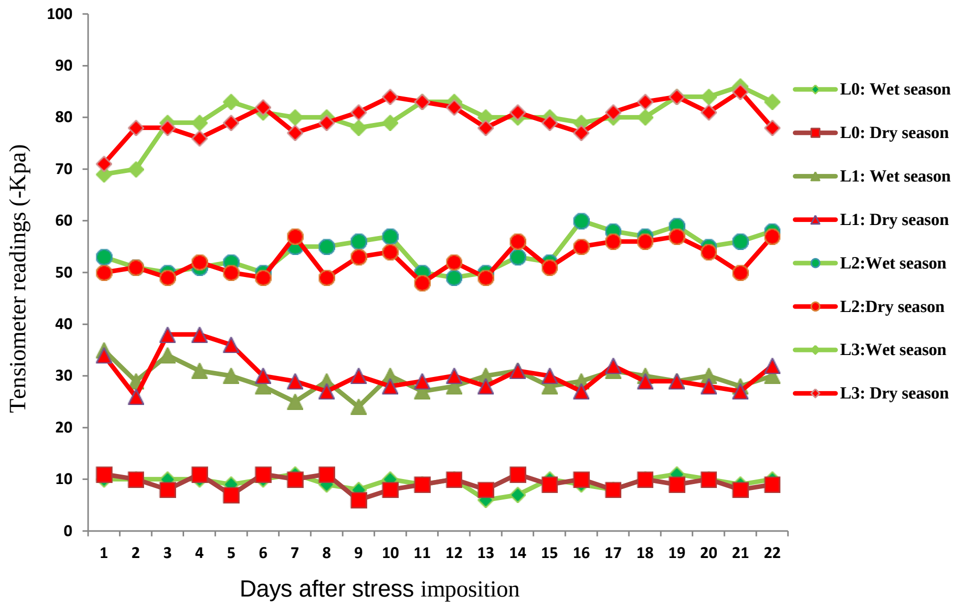

Figure 1. Fluctuations of tensiometer readings during the stress periods.

Variation of Grain Quality Indicators

Percentage of grain quality indicators variation was calculated using the value of the quality indicator when soil moisture level is L0 as 100%. For example, the variation in percentage of Amylose content at soil moisture level = L3 which can be indicated by %A3 is calculated as follow:

$$\% A3 = \frac{A0 - A3}{A0} * 100$$

Data were analyzed using SPSS 16 software. Data were subjected to one way analysis of variance (ANOVA) followed by Newman-Keuls's significant-difference test (P<0.05) to determine the differences in the parameters among the samples.

RESULTS

Soil Properties And Environmental Conditions

The chemical analysis of topsoil in the 0 to 20 cm range showed pH(H_2O) of 5.6, total organic carbon content (OC) of 1.6%, total nitrogen (N) of 0.161%, available phosphorus of 12.4 ppm, calcium: 3.9 $mgkg^{-1}$, magnesium: 0.72 $mgkg^{-1}$; potassium: 0.23 $mgkg^{-1}$; sodium: 1.1 $mgkg^{-1}$; ECEC: 4.98 $mgkg^{-1}$;zinc: 24.75 mgg^{-1};molybdenum: 120.49 $mgkg^{-1}$; iron: 66.74%; sand: 77%; clay: 6%; silt: 17%; Textural class Loamy sand. Mean of Air Temperature, Air humidity, wind speed, solar radiation and rainfall during the experimental periods are summarized in Table 1. It can be clearly noticed in Table 1 that the water stress was not disturbed by the rainfall during both years' experiments. As seen by the variation pattern of the tensiometer readings in Figure 1, it can be concluded that soil moisture content successfully maintained at each required soil moisture level.

Quality Parameters

The results of this study clearly showed that the targeted grain quality indicators either increased or decreased when soil moisture content varied at reproductive stage demonstrating that soil water availability which matched with water stress level can improve or decrease rice grain quality indicators. Head rice ratio of all the stressed

Table 2. Head rice ratio of tested varieties during dry season 2013 and wet season 2014.

Stress intensity	Period	NERICA 1	NERICA 4	NERICA 7	ARICA 4	ARICA 5
L0	DS 2013	56.9	57.1	50.9	57.1	56.3
L1		51.8	52.6	48.0	54.0	55.0
L2		43.6	47.2	41.8	46.8	45.2
L3		37.9	37.3	35.9	31.9	32.9
Mean		47.5	48.6	44.2	47.5	47.4
CV(%)		17.8	17.6	15.2	23.7	22.9
LSD		2.2	2.4	1.6	3.0	1.7
L0	WS 2014	56.9	56.7	51.20	56.8	55.9
L1		51.5	52.3	48.3	52.2	54.7
L2		43.2	46.9	41.6	46.4	44.8
L3		37.4	36.8	35.6	31.5	32.3
Mean		47.2	48.2	44.2	46.7	46.9
CV(%)		18.2	17.8	15.8	23.6	23.3
LSD		2.3	1.7	1.7	2.4	1.8

Notes: DS = dry season; WS = wet season.

Table 3. Amylose content of tested varieties during dry season 2013 and wet season 2014.

Stress intensity	Period	Nerica 1	Nerica 4	Nerica 7	Arica 4	Arica 5
L0	DS2013	28.3	28.3	29.0	27.3	25.6
L1		26.8	26.5	27.5	26.1	24.9
L2		21.4	22.0	21.7	20.2	22.7
L3		18.7	18.0	18.6	18.3	18.5
Mean		23.8	23.7	24.2	22.9	22.9
CV (%)		18.1	19.5	20.3	19.2	14.0
LSD		0.73	0.5	1.3	1.7	1.9
L0	WS2014	28.2	28.40	29.1	28.4	26.0
L1		26.7	26.2	27.4	26.0	25.2
L2		21.4	21.9	21.5	20.0	22.6
L3		18.4	18.1	18.3	18.5	18.6
Mean		23.7	23.6	24.1	23.2	23.1
CV (%)		19.4	19.3	21.0	20.5	14.5
LSD		1.2	0.9	1.5	1.97	1.1

Notes: DS = dry season; WS = wet season .

varieties decreased significantly ($P < 0.05$) when compared to control condition (L0) as shown in Table 2. The highest levels of reduction regarding HRR was recorded with ARICA varieties; 44 and 42% reduction with ARICA 5 and ARICA 4 respectively, (Figure 2) while HRR reduction for NERICA varieties ranged from 30 to 35% under severe water deficit (L3) (Figure 2). NERICA 7 had the lowest HRR reduction and NERICA 4 the highest under severe water deficit conditions Figure 2. Under well-watered (Lo) conditions, NERICA varieties showed the highest amylose content (average amylose content of 29%) as compared to ARICA varieties (27%) (Table 3). Amylose content significantly decreased with the scarcity of soil water (moisture content) for all the genotypes (Table 3).

The highest percentages of reduction of grain amylose content were observed with NERICA varieties. When compared to well-watered condition, the average percentage of reduction was about 36% for NERICA varieties while an average percentage of reduction of 31% was observed for ARICA varieties (Figure 2). Unlike the amylose content, an increase in grain protein content was observed for each variety (Table 4).The increase ofthis indicator of grain quality traits was more noticeable (>21%) concerning NERICA varieties while ARICA varieties showed an average increase of protein content of 19% under severe water deficit. Gel consistency values was significantly ($P < 0.05$) decreased under water stress in all the varieties. Under severe water stress condition the lowest value of gel consistency was found with NERICAs (average gel consistency of 65.7 mm) (Table 5) and the highest percentage of reduction (14%) was found with NERICA 1 (Figure 2).

DISCUSSION

The percentage of head rice ratio is one of the most

Table 4. Protein content of tested varieties during dry season 2013 and wet season 2014.

Stress intensity	Period	Nerica 1	Nerica 4	Nerica 7	Arica 4	Arica 5
L0	DS 2013	9.4	9.3	9.0	9.0	9.0
L1		9.4	9.3	9.0	8.8	9.1
L2		9.8	10.0	10.2	9.7	9.6
L3		10.8	9.9	11.6	11.0	10.0
Mean		9.9	9.6	10.0	9.6	9.5
CV (%)		6.7	4.4	12.3	10.2	4.8
LSD		0.8	1.2	0.8	1.5	1.0
L0	WS 2014	9.0	9.3	8.5	9.0	9.0
L1		9.3	9.0	9.0	9.2	9.2
L2		9.8	9.9	10.0	9.8	9.8
L3		10.9	11.1	11.7	11.2	10.8
Mean		9.8	9.8	9.8	9.8	9.7
CV (%)		8.5	9.2	14.4	10.2	8.1
LSD		0.4	0.5	1.0	0.6	0.5

Notes: DS = dry season; WS = wet season.

Table 5. Gel consistency of tested varieties during dry season 2013 and wet season 2014.

Stress intensity	Period	Nerica 1	Nerica 4	Nerica 7	Arica 4	Arica 5
L0	DS 2013	76.4	71.6	74.3	75.4	75.3
L1		74.6	71.2	73.6	75.0	75.0
L2		67.9	67.3	69.1	70.8	69.2
L3		66.0	66.1	66.6	68.5	68.4
Mean		71.2	69.1	70.9	72.6	72.1
CV(%)		7.1	3.1	5.2	4.7	5.4
LSD		1.4	1.3	1.3	1.0	1.0
L0	WS 2014	76.2	72.0	74.2	75.6	75.5
L1		74.6	71.1	73.3	75.1	74.9
L2		67.7	67.0	69.9	70.8	69.5
L3		65.7	65.8	66.4	68.1	68.2
Mean		71.1	69.0	70.9	72.4	72.0
CV(%)		7.2	4.3	5.0	5.0	5.2
LSD		1.2	1.4	1.0	1.0	1.5

Notes: DS = dry season; WS = wet season.

important criteria of selection of rice (milled rice) in West Africa (Sakurai et al., 2006; Fofana et al., 2010a).The head rice ratio is a measure of milling quality and hence, economic value (Futakuchi et al., 2013). A proportion of 50% of head rice or less is generally undesirable since it means that 50% of the rice is discarded as husk and bran after milling. In this study result shows that the head rice of the each variety decreased with the level of water deficit (water stress intensity). The decrease in the head rice ratio observed could be due to the increase of chalkiness related to improper grain filling as reported by Fofana et al. (2011) or fissured grain. A study carried out by Sakurai et al. (2006) in urban area in Ghana showed that rice varieties with high proportion of head rice were sold with higher price in the market. Based on the results of this study, it appeared clearly that water stress occurring during the reproductive stage reduced the market quality of rice.

Results showed that the head rice ratio of NERICA varieties decreased less than those of ARICA varieties under stress conditions, thus, in the communities where high percentage of head rice ratio is the most preferred type for farmers, consumers and others stakeholders in rice value chain, cultivation of NERICA varieties should be recommended instead of ARICA varieties. Similarly, ARICA varieties could be suitable in drought prone area where high broken rice types are preferred like Senegal. Cooking and eating characteristics are largely determined by the properties of the starch that makes up 90 percent of milled rice (Juliano et al., 1965; Futakuchi et al., 2008). Amylose content, gel consistency and gelatinization temperature are the important starch properties which influence cooking and eating characteristics. Amylose content and gel consistency have been considered as key indicators relating to rice eating quality (Juliano et al., 1965; Cagampang et al., 1973). Generally, rice

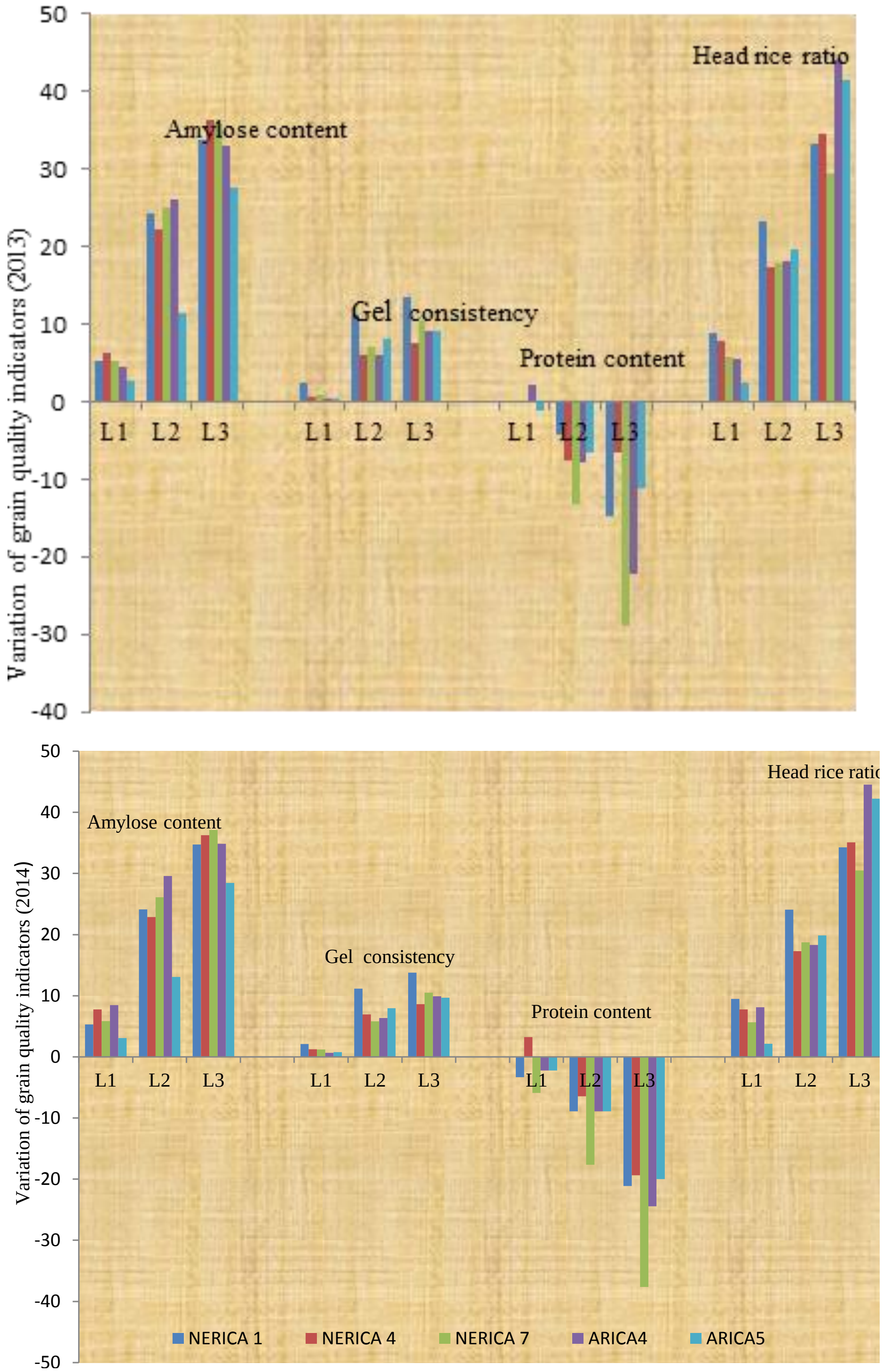

Figure 2. Variations (in percent) of grain quality indicators related to soil moisture content.

consumers, prefer the rice with intermediate apparent amylose content and gel consistency (Huang et al., 1998). Resurreccion et al. (1977) reported that high temperature decreased amylose content of IR20 and Fujisaka, similar results were obtained by Asaoka et al. (1985) who studied other japonica cultivars. Result from this study indicate that water deficit during the reproductive phase reduced the amylose content and the gel consistency of all the varieties regardless of trial. Several studies have shown that changing amount of amylose induced differences in rice grain quality (Krishnasamy and Seshu, 1989). Lyon et al. (2000) reported that there was a negative correlation between decreases in amylose and appearance of grain after cooking. Jane et al. (1999) showed that rice pasting properties are affected by amylose content and by the branch chain length distribution of amylopectin.

The amylose content is generally thought to be a critical determinant of starch pasting properties because amylose suppresses starch swelling. The amylose helix has an internal hydrophobic tube, providing a space for hydrophobic complexing agents such as lipids (Godet et al., 1993). Amylose-lipid complexes restrict granule swelling, which consequently affects pasting (Biliaderis and Tonogai, 1991). Hence, the apparent amylose content was negatively correlated with flour swelling volume and stickiness and was positively correlated with the hardness of cooked rice (Juliano, 1985). Based on the result of this study, it can be predicted that severe water deficit under reproductive stage makes both tested varieties sticky and less swelling. Protein is one of the factors that mainly influence the eating quality of rice (Adu-Kwarteng et al., 2003; Futakuchi et al., 2008). Protein content correlates with cooked rice texture. Protein is also involved in providing structural support to the rice kernel during cooking, thereby restricting starch granule swelling. Thus, treatment with protease, an enzyme that cleaves protein, significantly decreases cooked rice firmness (Saleh and Meullenet, 2007). Negative correlation was found between amylose content and protein content for stressed samples in this study. These results were similar to those of Koutroubas et al. (2004) and Fofana et al. (2010). The increase of protein content in the varieties under severe water stress condition will greatly improve the nutritional status of West African peoplebutthe protein content should be taken with care since it negatively correlates with rice taste (Futakuchi et al., 2008).

CONCLUSION

The study clearly showed changes in rice grain quality indicators (Head rice ratio, Amylose Content, Protein content and Gel consistency) when soil moisture stress occurs during the reproductive stage. The trend in changes of grain quality indicators was similar for each variety indicating that from the earliest generation of rice tested (NERICA) to the last generation (ARICA) there was no genetic gain in terms of changes of grain quality traits under reproductive water stress conditions. However, from the study, it appears that the occurrence of water deficit at reproductive stage affects rice grain quality, but it could not be stated that the water stress improves or decreases rice grain quality. Further studies are required to fully understand the effect of water stress on rice grain quality.

ACKNOWLEDGEMENTS

Funding for this study provided by the European Union (UE) through HAAGRIM project is acknowledged with gratitude. The authors are also grateful to SANGARE Hasane and MILOGO Walter of chemistry and Plant Biology and Ecology laboratories of University of Ouagadougou for assisting and data collection. We also sincerely thank Africa Rice (Ibadan/Nigeria) physiology team for helping in field experiments.

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