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Growth and yield characteristics of upland rice cultivar NERICA-4 grown under paddy field condition

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Abstract

The productivity of crops depends on cultivation methods, soil fertility, biotic and abiotic factors affecting the crop yield. It is necessary to understand the growth, yield and quality characteristic of a crop in various cultivation methods for achieving better yield and quality. The objectives of this study were to evaluate growth, yield and grain quality performance of upland rice cultivar (NERICA-4) under paddy field conditions and to compare it with other lowland cultivars. Three lowland cultivars (IR-28, Koshihikari and Nipponbare) and one upland cultivar (NERICA-4) were used. Fertilizers as a basal (N, P_2O_5, K_2O: 60, 100, 60 kg ha^{-1}) and top dressing (20, 0, 30) were applied. Three seedlings were manually transplanted on 16 May 2012, in a randomized complete block design. Compared to other cultivars, NERICA-4 was found to become mature earlier and produced lower stem number per square meter, dry weight, leaf area index, chalky grain, and rough rice yield. However, it produced the highest number of spikelets per panicle and nitrogen contents, followed by IR-28. The yield of NERICA-4 was (5.7 ton/ha), slightly lower than other cultivars. The highest percentage of cracked grain was observed in IR-28 followed by NERICA-4. It was caused by the rainy condition and fluctuating temperature at maturity, leading to the expansion of cracks in individual grain. These results suggest that, upland condition is more suitable for NERICA-4 culturing and harvesting than the paddy field because, for the identical amount of yield, the upland condition needs less amount of water than the paddy field condition.

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Introduction

Upland rice (*Oryza sativa* L.) is cultivated on nearly 20 million hectares in various countries of the world. It had growing area about 60 % in Asia, 30 % in Latin America and 10 % in Africa. More than 50 % of Asia upland rice is grown in south Asia (Hari *et al.,* 1994). Rice ecosystems in West Africa are categorized into upland, rain-fed lowland, irrigated lowland, immeasurable water, and floating ecosystems (Tobita, 2002). The upland ecosystem inhabits 40 % of the total rice ecosystem area, but its productivity is very poor (around 1 ton/ha) due to drought, soil acidity, weeds and lack of nitrogen (Tobita, 2002). NERICAs are the interspecific progenies of *Oryza sativa* and *Oryza glaberrima,* which have been bred by Africa Rice Center (formerly West Africa Rice Development). The creations of breeding NERICA was to incorporate the great traits of two species: the stress tolerance of *Oryza glaberrima* and high-yielding capacity of *Oryza sativa*. So far, three types of NERICA have been bred for prey ecosystems: upland, irrigated lowland, and rain-fed lowland (Futakuchi, 2008).

However, the upland rice-cultivation area is reasonably little compared with that lowland rice: 7 % of total rice grown area in Asia and 0.2 % in Japan (Maclean, 2002). Nevertheless, upland rice plays a major role in crop rotation because it can reduce damage caused by ongoing cropping (Matsunam *et al.,* 2011). The yield of upland rice often reduces when the water supply gets less (Kato *et al.,* 2006). Rice plants are unable to use soil water in the deeper layers, due to their root system is superficial than that of other crops (Angus *et al.,* 1983).

Although, the productivity of crops depends on cultivation methods, soil fertility, biotic and abiotic factors which either directly or indirectly affects its growth and yield. The cultivars have different physiological and morphological characteristics that contribute to yield (Yang *et al.,* 2007). The yield of rice can be enhanced by improving fertilization, irrigation management and good pest and disease control.

For stable crop production, knowledge of varietal, morphological and physiological characteristics is necessary. However, to clarify these discrepancies and ascertain the significant determinants of productivity under the paddy field condition, we compare the growth, yield and grain quality performance of upland rice cultivar (NERICA-4) under paddy field conditions and to compare with other lowland cultivars.

Materials and methods

Experimental design and plant cultural

Experiment was conducted at Tsukuba International Center, Japan (36°32' N, 140°25' E) from April to September 2012. Three lowland cultivars (IR-28, Koshihikari and Nipponbare) and one upland rice cultivar (NERICA-4) were used. The experiment was laid out in Randomized Complete Block Design (RCDB) with three replications and twelve plots. The four rice cultivars were randomly arranged in each plot (3.6 m × 5.7 m for each cultivar), separated by a distance of 50cm between blocks and 50 cm between plots within a block. The experimental field was puddled mechanically by power tiller and manually leveled, the fertilizers as a basal dressing were applied in the field by the broadcasting method at the rate of (N, P_2O_5, K_2O: 60, 100, 60 kgha^{-1}) and top dressing (20, 0, 30) were applied, respectively at the panicle initiation stage.

The pre-germinated seeds were sown in nursery boxes (60 cm x 30 cm) at the rate of 80 gr per box. The seedlings, with average 3.4 plant age in leaf number, were treated with a fungicide at 50 g per box against blast. The planting density was 22.2 hills per square meter at spacing (30 cm × 15 cm). Three seedlings per hill were manually transplanted by hand on 16 May 2012. The water level of 4-5 cm depth was maintained during whole growth periods.

Data Collection

Growth parameters, yield components and grain characteristics

For the measuring the growth parameters starting from transplanting until maturity stage.

Six hills per plot were sampled in different growth stages of each treatment and the samples were put into separate bags and dried in the oven at 80 °C for 48 hours and then their growth parameters (Plant length, stem number per square meter, dry matter and leaf area index) were measured. At maturity, 48 hills and 38 hills were uprooted and air-dried in a greenhouse for three weeks. The averaged sized hills per plot were thereafter selected to determine yield and yield components (panicle length, panicle number per meter square, spikelet number per panicle, the percentage of ripened grains, 1000-grain weight and rough rice yield), respectively.

We separated filled and unfilled grains using salt solution with specific gravity of 1.06 by using hydrometer followed the method explained by Hoshikawa (1989) for japonica (Koshihikari and Nipponbare) and for IR-28 and NERICA-4 cultivars 1.03 specific gravity was used, respectively. The 1000-grain weight of rice in each cultivar was determined at a moisture content of 14 %, measured using a grain moisture tester (Model No. PB-1D2, Series No. BD-04623, by Kett-Japan). Finally, calculated the yield and yield components followed the method described by Hoshikawa (1989).

At maturity stage, 10 panicles were randomly selected, dried at the room temperature and their grain characteristics including grain size (grain length and width) and various characteristics (white belly, white core, chalky and cracked grain) were measured. Chemical elements (nitrogen, phosphorus and potassium) contents in plant tissue (stem, leaf and panicle) were measured and analyzed at maturity stage. Nitrogen content was measured through Automatic High Sensitive NC analyzer (NC-22F Sumigraph) followed the method of Dumas (Bremner, 1996), Phosphorus through Spectrophotometer (Model No. UV mini-1240v, Serial No. A10953800314 YS by Shimadzu Corporation, Japan) by the following method; The panicles, leaves and stems were dried in an oven at 80 °C for 48 hours thereafter were grinded to powder, then these samples through Cyclone Sample Mill (Model No. 3010-030, S/N 6052, by Shizuoka Udy Corporation, USA) and were analyzed in the aforementioned NC analyzer and followed the method of sulphomolybdo-phosphate blue method (Kuo, 1996). The potassium was measured through Atomic Absorption Spectrophotometer (Model No. AA-6650F, Serial No. A30483700027 S3 by Shimadzu Corporation, Japan) and followed the method of Wright *et al.*, (1996).

Statistical analysis

The variances of the data were analyzed by variance analysis (ANOVA) with SPSS software 13.0 the means were compared using Tukey's high significant difference (HSD) at the 5% level.

Results and discussion

The results revealed that NERICA-4, which is an upland cultivar, was found to be an early maturing cultivar. This could be an effective trait to flee drought or rival with weeds (Somado *et al.,* 2008). IR-28 and Koshihikari were shown almost identically and longer growth durations compared to other cultivars (Table. 1). Short maturing cultivars have short vegetative growth stages. As a result, they may have started panicle primordia before the maximum tillering stage. In addition, the heading may be confounded, because subsequent tillers may produce panicles (Yoshida, 1981).

Table 1. Different rice cultivars characteristics and growth dates.

Cultivars	Ecosystem	Transplanting (Month/day)	Panicle initiation	Heading Date	Maturity stage	Growth duration (days)
IR-28	Lowland	5/16	7/13	8/2	9/10	114
NERICA-4	Upland	5/16	7/7	7/28	8/31	108
Koshihikari	Lowland	5/16	7/13	8/3	9/7	115
Nipponbare	Lowland	5/16	7/23	8/10	9/14	122

Same letters in two columns and different letters under same title indicate not significant and significant difference at the 5% probability level.

Growth parameters

The tallest plant length (117.0 cm) at maturity were achieved from Koshihikari followed by IR-28 (111.8 cm) and NERICA-4 (107.1 cm), respectively. Nevertheless, Nipponbare produced plants with the shortest length (102.5 cm) at maturity (Table 2). The number of stem per square meter was significantly lower in NERICA-4 at different growth stages compared to other cultivars due to its genetic variation. On the other hand, Koshihikari (421.8) and Nipponbare (405.8) cultivars showed the significantly higher number of stem per square meter at maturity stage (Table 3). The higher tillering ability in the three cultivars leads to higher production of dry matter, resulting in higher production of rice yield. Therefore, the higher tillering ability may directly determine grain yield as noted by Yoshida *et al.,* (1972). In addition, tiller number determines panicle number per hill and consequently, grain yield (De Datta, 1981),

The higher dry matter production implies higher starch accumulation resulting in higher yields. Nipponbare showed significantly higher (7.3 ton/ha) dry matter at panicle initiation, full heading (12.53 ton/ha) and maturity stages (16.3 ton/ha) than other cultivars did (Table 4). On the other hand, NERICA-4 attained significantly lower dry matter at different stages compared to others. It was due to the lower number of stems produced by this cultivar, compared to others. Yoshinaga *et al.,* (2006) informed that late heading cultivars produced higher dry matter at full heading and maturity stages. The present study confirmed these earlier findings as Nipponbare being a late maturing genotype attained the maximum dry matter. The decreased dry matter accumulation leads to the increase of smaller or imperfect grains (Yoshida, 1981. Toshiro and Wardlaw, 1991). The higher production of dry matter weight may be influenced by the ability of the cultivar to produce a higher number of stem per square meter. In addition, the cultivar that accumulated higher dry matter had maintained higher photosynthetic activity and acquired superior yields (Ke Zhand and Zhang, 2014).

NERICA-4 and Nipponbare attained the lowest and the highest leaf area index, respectively. It was likely due to corresponding of stems in these cultivars (Table 5). Nipponbare synthesized more photosynthates and hence produced higher dry matter compared to NERICA-4.

The leaf area index may contribute to dry matter production and rough rice yields. *Japonica* and IR-28 (*Indica*) cultivars achieved statistically identical leaf area index at different growth stages. Our results amplified the findings of Maruyama *et al.,* (1988), who observed identical leaf area index values from japonica and indica cultivars at full heading stage. Ishizuka and Tanaka (1953) stated that the leaf area of a rice population is a factor closely related to grain production because the leaf area at flowering stage greatly affects a number of photosynthates accessible to the panicles.

Hence, these photosynthate products obtainable in the panicle is easily assimilated to the spikelets. The low total leaf area in a rice population leads to low production of photosynthate products available in the panicles, which can result in a higher percentage of unfilled spikelets, as observed in NERICA-4. The leaf area index (LAI) has a positive correlation with grain yields in the crops (Yoshida and Parao, 1972).

Table 2. Plant length (cm) of rice cultivars at various growth stages.

Cultivars	Transplanting	Panicle initiation	Full heading	Maturity stage
NERICA-4	22.0 ^{b}	69.7 ^{ab}	104.8 ^{ab}	107.1 ^{ab}
IR-28	16.1 ^{c}	64.5 ^{b}	104.9 ^{ab}	111.8 ^{ab}
Koshihikari	23.5 ^{a}	72.0 ^{ab}	114.9 ^{a}	117.0 ^{a}
Nipponbare	23.5 ^{a}	76.0 ^{a}	100.6 ^{b}	102.5 ^{b}

Same letters in two columns and different letters under same title indicate not significant and significant difference at the 5% probability level.

Table 3. Number of stems m^{-2} of rice cultivars at various growth stages.

Cultivars	Transplanting	Panicle initiation	Full heading	Maturity stage
NERICA-4	66.6 ^{a}	384.8 ^{b}	272.6 ^{a}	259.0 ^{c}
IR-28	66.6 ^{a}	571.0 ^{a}	420.6 ^{a}	329.3 ^{b}
Koshihikari	66.6 ^{a}	569.8 ^{a}	474.8 ^{b}	405.8 ^{a}
Nipponbare	66.6 ^{a}	577.2 ^{a}	510.6 ^{a}	421.8 ^{a}

Same letters in two columns and different letters under same title indicate not significant and significant difference at the 5% probability level.

Table 4. Dry matter (ton/ha) of rice cultivars at various growth stages.

Cultivars	Transplanting	Panicle initiation	Full heading	Maturity stage
NERICA-4	0.02 ^{a}	3.9 ^{b}	8.4 ^{b}	12.0 ^{b}
IR-28	0.02 ^{a}	5.4 ^{b}	10.7 ^{ab}	14.4 ^{ab}
Koshihikari	0.02 ^{a}	4.8 ^{b}	11.5 ^{a}	15.2 ^{ab}
Nipponbare	0.02 ^{a}	7.3 ^{a}	12.5 ^{a}	16.3 ^{a}

Same letters in two columns and different letters under same title indicate not significant and significant difference at the 5% probability level.

Table 5. Leaf area index of rice cultivars at various growth stages.

Cultivars	Transplanting	Panicle initiation	Full heading	Maturity stage
NERICA-4	0.04 ^{a}	2.8 ^{b}	2.8 ^{b}	1.2 ^{a}
IR-28	0.03 ^{a}	3.4 ^{ab}	4.3 ^{ab}	1.7 ^{a}
Koshihikari	0.03 ^{a}	3.1 ^{b}	4.3 ^{ab}	1.5 ^{a}
Nipponbare	0.03 ^{a}	4.5 ^{a}	5.0 ^{a}	2.5 ^{a}

Same letters in two columns and different letters under same title indicate not significant and significant difference at the 5% probability level.

Yield and yield components

No significant differences in panicle lengths (cm) were observed among cultivars except Koshihikari, which showed the shortest panicle length (17.9 cm) among cultivars (Table 6).

The maximum number of panicles per square meter was produced by japonica (Koshihikari and Nipponbare) because of higher stem numbers (Table 6). However, the lowest number of panicles (246.3) was produced by NERICA-4 followed by IR-28 (343.1). The lowest number of panicle per square meter in NERICA-4 was due to a fewer number of stem numbers produced by this cultivar.

The highest number of spikelets per panicle (106.2) was achieved in NERICA-4 followed by IR-28. However, Koshihikari (72.9) and Nipponbare (70.5) achieved statistically equivalent lowers number of spikelets per panicle with each other (Tab 6). The highest spikelet production by NERICA-4 may have led to high competition of assimilated nutrients during ripening stage. That achieved more spikelets becoming sterile (unfilled) as a result recorded, the lowest percentage of ripened grains and variations in spikelets number can be attributed to the genetic nature of different cultivars.

High percentage of ripened grain was observed in japonica (Koshihikari and Nipponbare) cultivars. On the other hand, IR-28 (71.9 %) and NERICA-4 (72.9 %) achieved lower percentage of ripened grain (Table 6). It was due to the high competition of nutrition at ripening stage and the probable influence of temperature during grain filling. These variations might be attributed to the acclimation of japonica in conditions of Tsukuba, Japan, which was more convenient than the acclimation of other cultivars.

Table 6. Yield and yield characteristics of different rice cultivars.

Cultivars	Panicle length (cm)	Number of panicles/m²	Number of spikelets/panicle	Ripened grains (%)	1000-grain weight (g)	Rough rice yield (ton/ha)
NERICA-4	21.7 [a]	246.3 [c]	106.2 [a]	72.2 [b]	29.7 [a]	5.8 [a]
IR-28	23.7 [a]	343.1 [b]	88.2 [ab]	71.8 [b]	29.5 [a]	6.8 [a]
Koshihikari	17.9 [b]	417.8 [a]	72.9 [b]	84.6 [a]	29.9 [a]	6.7 [a]
Nipponbare	21.4 [a]	417.0 [a]	70.5 [b]	82.0 [ab]	28.5 [a]	6.5 [a]

Same letters in two columns and different letters under same title indicate not significant and significant difference at the 5% probability level.

There were no significant differences in 1000-grain weight and rough rice yield among cultivars. The highest rough rice yield was achieved by IR-28 (6.8 ton/ha), followed by Koshihikari (6.7 ton/ha) and Nipponbare (6.5 ton/ha), respectively (Table. 6). Ju *et al.,* (2006) found that the cultivars that showed a high grain yield retained a higher number of panicle and spikelets number while increasing nitrogen absorption resulted in an increase in the number of spikelets and grain yield.

The lowest rough rice yield was observed in NERICA-4 (5.7 ton/ha), due to lower stem and panicle numbers compared to other cultivars. While, the grain yield of NERICA-4 was reported (5.0 ton/ha) in upland condition, despite by applying less amount of fertilizers (Somado *et al.,* 2008).

Sulaeman *et al.,* (2011) observed variable grain yields under different conditions. Yoshinaga *et al.* (2013) observed that, on the high-yielding cultivar of rice, the most important factor in determining yield is the high accumulation of total number of spikelet per unit area, a thousand grain weight and grain filling ability which related to sink size capacity.

Two of the three important growth characteristics for obtaining a higher yield according to (Yoshida *et al.,* 1972) are having the higher tillering ability, short culms, and stiff culms. Therefore, any rice cultivar that exhibits the higher tillering ability and short culms may produce a greater amount of rice yield.

To get higher rough rice yield very much depends on the spikelet number per unit area of the panicle number type cultivar (Yao *et al.,* 2000; Peng *et al.,* 1999).

Nutrients contents in panicle, leaf and stem at maturity stage

Relatively higher nitrogen contents were observed in leaves followed by panicles among cultivars (Fig. 1). Nitrogen contents in panicle, leaf and stem were higher in NERICA-4 followed by IR-28 compared to japonica (Koshihikari and Nipponbare) rice cultivars.

The higher nitrogen content could be either due to higher nitrogen requirements of these cultivars or efficient nitrogen absorption from the soil. The increase in nitrogen absorption appeared higher grain yields (Ju *et al.,* 2006).

Many scientists (Guindo, 1994; Peng, 2002; Liu, 2007; Yang *et al.,* 2010) stated that nitrogen is an essential nutrient for the growth and the yield of rice. The poorer number of stems in NERICA-4 reduced competition and contributed towards higher leaf nitrogen content.

This reduction of nitrogen content in leaf and stem was due to translocation of nutrients towards grains. Fukushima *et al.,* (2011) found that at full heading stage, total nitrogen (g/m^{-2}) and leaf nitrogen percentage hardly differed within cultivars.

Therefore, it remained almost identical in different cultivars. Higher nitrogen use efficiency of large panicle size cultivar Akita-63 resulted in large sink size (Mae *et al.,* 1996). In our study, japonica (Koshihikari and Nipponbare) cultivars were more efficient because, these cultivars achieved the same dry matter with less nitrogen content. It was reported that nitrogen use efficiency increased in improved rice cultivars (Yoshida *et al.,* 2006).

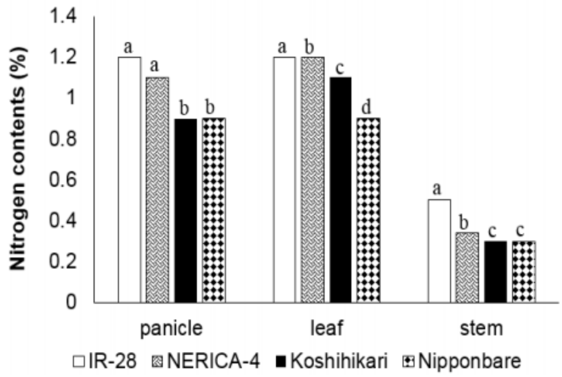

Fig. 1. Nitrogen contents (%) in panicle, leaf and stem in different cultivars at maturity stage. Same letters in two columns under same title indicate no significant difference at the 5% probability level.

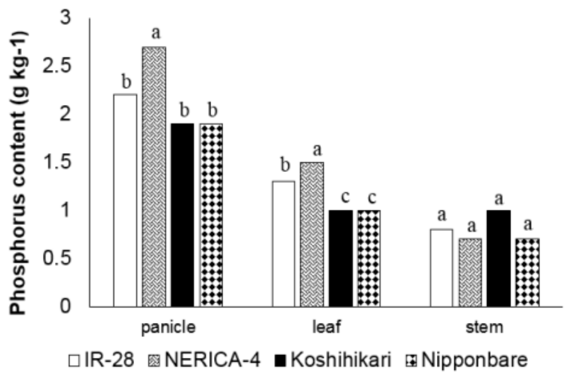

Fig. 2. Phosphorus content (g kg^{-1}) in panicle, leaf and stem in different cultivars at maturity stage. Same letters in two columns under same title indicate no significant difference at the 5% probability level.

Higher content of phosphorus was observed in panicle compared to leaf and stem at maturity stage in all cultivars. The contents of phosphorus and nitrogen are usually higher in the panicle compared to leaf and stem (Yoshida, 1981). NERICA-4 showed higher phosphorus content in panicle (2.7g kg^{-1}) and in the stem (1.5g kg^{-1}).

However, japonica (Koshihikari and Nipponbare) showed lower phosphorus contents in all three parts of their plants (Fig. 2). Contrary to nitrogen and phosphorus contents, potassium accumulated in stem more than in leaf and panicle. It was probably due to translocation of potassium towards the stem.

Significantly highest potassium content was observed in IR-28 (41.9g kg^{-1}) followed by NERICA-4 (31.9g kg^{-1}) in the stem compared to japonica (Koshihikari and Nipponbare) rice cultivars (Fig. 3). Potassium is an essential nutrient in the initiation of enzymes, such as starch combinatorial (Nitsos and Evans, 1969). Japonica cultivars showed statistically identical potassium contents in leaves and stems among each other, but significantly lower than other cultivars.

However, japonica (Koshihikari and Nipponbare) cultivars were more nutrient efficiency as they achieved statistically similar dry matter weight with poorer values of nutrients.

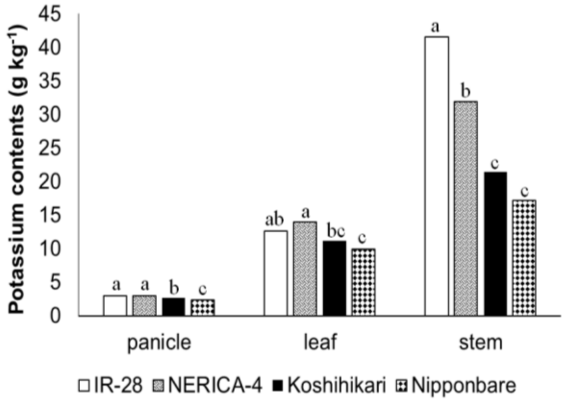

Fig. 3. Potassium contents (g kg^{-1}) in panicle, leaf and stem in different cultivars at maturity stage. Same letters in two columns under same title indicate no significant difference at the 5% probability level.

Rice grain quality

Significantly, higher white belly (13 %), white core (8 %) and chalky grains (30.7 %) were observed in IR-28 followed by japonica (Koshihikari and Nipponbare) rice cultivars (Table 7). Significantly higher cracked grain was observed in IR-28 (61.4 %) followed by NERICA-4 (26.5 %), whereas Koshihikari and Nipponbare showed no cracked grain (0 %) among others.

The grain length in IR-28 (7 mm) was higher than the one in japonica (Koshihikari and Nipponbare), but was statistically indifferent with the one in NERICA-4. While, the grain length (7.2 mm) and width (2.5 mm) of NERICA-4 has been reported in the upland condition (Somado *et al.,* 2008).

Table 7. Total evaluation for grain appearance in difference rice cultivars

Cultivars	White belly (%)	White core (%)	Chalky grain (%)	Crack grain (%)	Grain length (mm)	Grain width (mm)	Total evaluation
IR-28	13.0 [a]	8.0 [a]	30.7 [a]	61.4 [a]	7.0 [a]	1.8 [bc]	Bad
NERICA-4	7.0 [c]	5.3 [c]	18.3 [d]	26.5 [b]	6.9 [a]	2.0 [b]	Moderate
Koshihikari	9.7 [b]	8.0 [a]	22.7 [b]	0.0 [c]	4.6 [c]	2.0 [b]	Good
Nipponbare	9.3 [b]	6.7 [b]	24.0 [c]	0.0 [c]	5.2 [b]	2.1 [a]	Good

Same letters in two columns and different letters under same title indicate not significant difference at 5% probability level.

Sun *et al.,* (2016) observed, the grain length of some cultivars of indica was longer than some cultivars of japonica. Grain length, width and thickness widely differ among cultivars (Yoshida, 1981). In this study, brown rice of japonica (Koshihikari and Nipponbare) cultivars showed good quality, NERICA-4 and IR-28 were appeared moderate and bad one-grain quality, respectively. The moderate quality of NERICA-4 and the bad quality of IR-28 were caused by the rainy condition and fluctuating temperature during the grain development of rice plants, leading to the expansion of cracks in individual grain.

Conclusion

Our findings revealed that NERICA-4 had lower rough rice yield and grain quality than the japonica (Koshihikari and Nipponbare) lowland rice cultivars under paddy field condition. The lower yield production ability of NERICA-4 seems to be due foremost lower tillering ability, showing in poorer number of panicles per square meter. However, the spikelet number per panicle was significantly higher in NERICA-4 than in japonica (Koshihikari and Nipponbare) rice cultivars. We contemplate this character to be one of the greatest influence determinants for grain yield under upland and lowland conditions. However, the results suggest that upland condition is more suitable for NERICA-4 culturing and harvesting and with better grain quality than the paddy field condition of Tsukuba, Japan because, for the identical amount of yield, the upland condition needs less amount of water and fertilizers than the paddy field condition.

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