academicJournals

Vol. 10(11), pp. 1177-1183, 12 March, 2015
DOI: 10.5897/AJAR2013.8389
Article Number: ABD367051383
ISSN 1991-637X

http://www.academicjournals.org/AJAR

African Journal of Agricultural Research

Full Length Research Paper

Yield, quality and profitability of rice (*Oryza sativa* L.) varieties grown in the eastern Himalayan region of India

L. K. Baishya*, D. Sarkar, M. A. Ansari and N. Prakash

ICAR RC for Neh Region, Manipur Centre Imphal, India.

Received 16 December, 2013; Accepted 11 March, 2015

Rice is a major staple food for over 3 billion people, representing the major carbohydrate and even protein source in South Eastern Asia, but also in Africa. Unfortunately, rice is a poor source of many essential micronutrients. Thus, a rice-based diet is the primary cause of micronutrient malnutrition throughout much of the developing world. Iron, zinc, and vitamin A deficiencies are common in rice-consuming regions. These deficiencies account for decreased work productivity, reduced mental capacity, stunting, blindness, increased child mortality, and elevated morbidity and mortality in general. Therefore, an experiment was conducted to study the performance of seven improved rice varieties introduced in the Eastern Himalayan Region of India with a local variety considering yield, grain quality for human nutrition and economic benefit under lowland condition. The highest grain yield was recorded in paddy variety, RC Maniphou 7 (5.3 t ha^{-1}) followed by RC Maniphou 11 (5.2 t ha^{-1}) over the indigenous paddy variety, Daramphou. These paddy varieties recorded 81 and 79% higher grain yield over the local variety and found to be highest profitable as compare to the other variety under the study. However, the grain nutritive value was found to be higher in the paddy variety RC Maniphou-5 followed by RC Maniphou-4. So, agronomic biofortification of rice with micronutrient might be an effective component of a food system strategy to reduce micronutrient malnutrition in rice eating populations. Evaluation of regression factor scores through principal component analysis using grain yield, grain quality and economic benefit has proved the superiority of RC Maniphou-7, RC Maniphou-10 and RC Maniphou-11 over the other improved and local varieties for the foothills of eastern Himalayan region.

Key words: Rice, yield, grain quality, economic benefit.

INTRODUCTION

Rice (*Oryza sativa* L.) is the main staple food for more than half of the world population (Sasaki and Burr, 2000). It provides around 21% of dietary energy and 15% of protein to global population (IRRI, http://irri.org/about-rice/rice-facts/rice-basics). It is the most important food grain crop in the north eastern hill agro-ecosystem of India in the eastern Himalayan region. It is occupying 3.5 million ha in the states of Arunachal Pradesh, Assam, Manipur, Meghalaya, Mizoram, Nagaland, Sikkim and Tripura, which accounts for more than 80% of the total

*Corresponding author. E-mail: lkbaishya@rediffmail.com

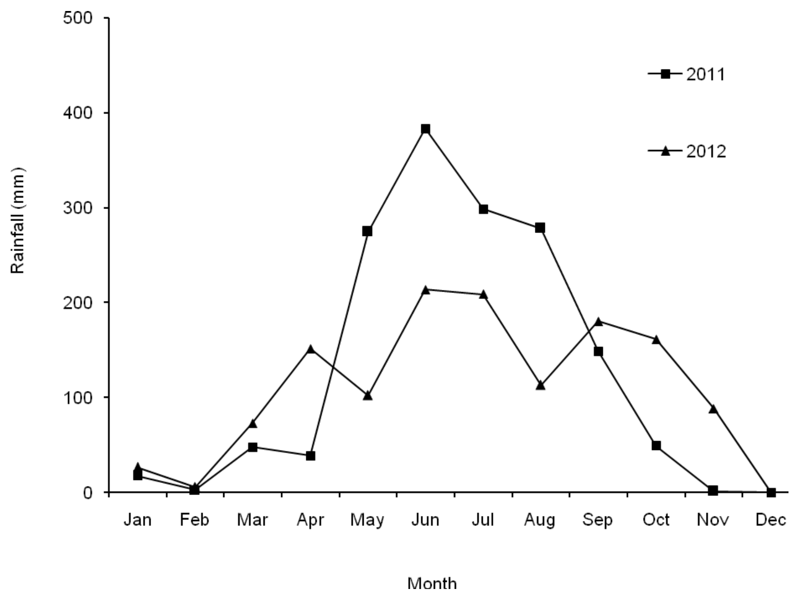

Figure 1. Distribution of monthly rainfall of the experimental site during 2011-2012.

cultivated area of the region (http://www.rkmp.co.in). The eastern Himalayan region of India is considered to be one of the hot pockets of rice genetic resources in the world and a potential rice-growing region with extremely diverse rice growing conditions as compared to other parts of the country. Being the secondary centre of origin of rice, the region is rich in diverse germplasm that shows the distinctness amongst them. Selection made unknowingly by various ethnic groups inhabiting at different altitudes and climatic situations, practicing different forms of cultivation might have also contributed to some extent towards the diversity of rice crop in this region (Hore, 2005). Although, during the post-green revolution period due to introduction of improved varieties, rice yield in north eastern region of India has been almost doubled, there is further scope for increasing its productivity, which remains much below the national productivity. Again, rice grain protein, available starch, dietary fiber, vitamin and macro- and micronutrients have wide variability among the cultivars (Eggum et al., 1993; Graham et al., 1999; Meng et al., 2005). Improved rice (*Oryza sativa* L.) varieties introduced in the eastern Himalayan region of India need to be assessed for their yield performance, nutritional quality and economic profitability. Therefore, it is desirable to have information about the rice varieties grown in a region with regards to their yield performance, nutritional quality and economic benefit. In this context, the present investigation has been under taken to compare yield, quality of grain for human nutrition and profitability of some of the improved rice varieties vis-à-vis a local variety grown under lowland rain fed condition of the eastern Himalayan region of India.

MATERIALS AND METHODS

Experiment

Field experiment was conducted during two consecutive years (2011 and 2012) at the Research Farm of ICAR Research Complex for NEH Region, Manipur, India (25.45° N, 93.53° E, 295 m above mean sea level). The site is representative of the foot hills of eastern Himalayan Region and falls under sub-humid region. It receives an average annual rainfall of 1433 mm (mean of the two years) of which 70% occurs during the rice growing season (June to October) (Figure 1). It also experiences mean annual daily minimum and maximum temperature of 21 and 31°C, respectively during the rice season. The experimental soil (0 to 0.15 m depth) is clay loam in texture, acidic in reaction (pH 5.15) and oxidizable organic carbon, available nitrogen, available phosphorus and available potassium are 46.5 g kg^{-1}, 238 mg kg^{-1}, 9 mg kg^{-1} and 156 mg ka^{-1}, respectively. Eight rice varieties (seven improved varieties released from ICAR Research Complex for NEH Region, Manipur such as RC Maniphou 4, RC Maniphou 5, RC Maniphou 6, RC Maniphou 7, RC Maniphou 10, RC Maniphou 11, RC Maniphou 12 and one indigenous local variety Daramphou) were grown in randomized block design (5 x 5 m plot size). The varieties were replicated thrice. The crop was sown at the 1st fortnight of June and harvested at physiological maturity in October. The crop was grown with recommended agronomic package of practices including fertilization, weeding and pest control. Grain and straw yield of rice was recorded at harvest and representative grain samples were collected for analysis.

Grain analysis

Nitrogen concentration in grain was determined by micro-Kjeldahl digestion and distillation (Nelson and Sommers, 1973). For determination of P, K, Fe, Mn, Cu and Zn plant samples were ashed in a muffle furnace at 550°C for 3 h and subsequently extracted with 2 N HCl. Then the extract was analyzed for P (vanadomolybdate yellow color method; Jackson, 1973), K, Fe, Mn,

Table 1. Formulae and units of different economic parameters.

Parameter	Formula	Unit
Gross return	Grain yield value + straw yield value	INR ha^{-1}
Net return	Gross return – cost of cultivation	INR ha^{-1}
Benefit to cost ratio	Gross return/cost of cultivation	--
Crop profitability	Net return/crop growth period in days	INR ha^{-1} d^{-1}
Market production efficiency	Economic yield/crop growth period in days	kg ha^{-1} d^{-1}
Biological production efficiency	Biological yield/crop growth period in days	kg ha^{-1} d^{-1}

Currency: one US Dollar = 55 Indian Rupees (INR), Grain price = 10800 INR Mg^{-1}, Straw price = 1200 INR Mg^{-1}, Growth period of RC Maniphou 4, RC Maniphou 5, RC Maniphou 6, RC Maniphou 7, RC Maniphou 10, RC Maniphou 11, RC Maniphou 12 and Darmaphou = 110, 115, 125, 135, 125, 125, 125 and 135 days, respectively.

Table 2. Yield attributing characters and yield of rice varieties.

Treatment	Plant height (cm)	Number of tillers per plant	Panicle length (cm)	1000 grain weight (g)	Harvest index (%)	Grain yield (t ha^{-1})	Straw yield (t ha^{-1})
RC Maniphou 4	84.5	13.4	21.3	28.93#	39#	3.9	6.0
RC Maniphou 5	82.6	15.2	21.1	29.47#	40#	4.1	6.1
RC Maniphou 6	95.3	11.3#	18.2	29.03#	39#	4.8#	7.3
RC Maniphou 7	99.1	17.5	24.5#	29.50#	42	5.3	7.8#
RC Maniphou 10	123.3	11.2#	23.0#	30.67	39#	4.9#	7.5
RC Maniphou 11	113.7	10.3#	22.2#	27.87	39#	5.2	7.8#
RC Maniphou 12	78.6	10.4#	22.5#	33.67	39#	4.2	6.3
Daramphou	144.2	9.6#	20.6	32.90	36	2.9	5.1
SEm±	1.86	0.83	0.75	0.37	0.73	0.07	0.11
LSD (p = 0.05)	5.71	2.53	2.30	1.13	2.24	0.23	0.34

Harvest index (%) = (economic yield/biological yield) x 100, #indicates the values are statistically at par with each other.

Cu and Zn (atomic absorption spectrometry, PerkinElmer). Protein and starch content in grain was analyzed in FOSS grain analyzer.

Quality index (QI)

Grain quality was assessed using linear indexing technique to integrate different parameters important for human nutrition, such as N, P, K, Fe, Cu, Zn, Mn, starch and protein content in rice grain. In this technique, each observation was divided by the highest observed value of that parameter so that the highest observed value received a score of one. Values of each of the selected quality parameters were summed up to get QI for each variety. The higher the index score better is the crop quality for human nutrition.

Economic analysis

Gross return, net return, benefit to cost ratio, crop profitability and production efficiencies were determined according to the procedures presented in Table 1. The analysis of variance for the effects of year, variety and year x variety interaction was computed using biomass yield, yield attributing characters and grain nutrient content of rice as dependent variables. Yield, yield attributes and nutrient content were not significantly influenced either by year or by year x variety interaction, which indicated that treatment effects were consistent across years. Therefore, data were pooled and presented across the years.

The relative strength of all the eight rice varieties were compared by employing non parametric evaluation of regression factor scores through principal component analysis (PCA) using yield, QI and BCR as goal variables. In this screening technique all components corresponding to eigen values more than one have been considered. The relative size of the eigen value associated with a particular component indicated the relative contribution of concerned component to the total variance of original data set. Regression scores were then ranked from 1 to 8 for the highest score as 1 and the least one as 8. Statistical analyses of the data were done using SPSS 17.0 (SPSS Institute Inc.).

RESULTS

Yield attributes

The results indicated that yield attributes of rice varieties respond differently under the same growing conditions (Table 2). Significant variations (p=0.05) in plant height, number of effective tillers per plant, panicle length, test weight of grain (1000 grain weight), grain, straw yield and harvest index were observed among the rice varieties

Table 3. Grain quality parameters and quality index of different rice varieties.

Treatment	Starch	Protein	Nitrogen	Phosphorus	Potassium	Iron	Copper	Zinc	Manganese	Quality index
	(%)					(mg kg^{-1})				
RC Maniphou 4	67.9$^{\#}$	8.4$^{\#}$	1.33$^{\#}$	0.35$^{\#}$	0.34	13.7	2.0$^{\#}$	17.0$^{\#}$	22.3$^{\#}$	8.1
RC Maniphou 5	66.4$^{\#}$	8.5$^{\#}$	1.43$^{\#}$	0.36$^{\#}$	0.38$^{\#}$	18.0	2.0$^{\#}$	17.6$^{\#}$	17.4	8.3
RC Maniphou 6	58.6	7.8	1.32$^{\#}$	0.36$^{\#}$	0.39$^{\#}$	14.3	1.8$^{\#}$	14.3$^{\$}$	22.3$^{\#}$	7.8
RC Maniphou 7	63.5$^{\#}$	8.8$^{\#}$	1.47$^{\#}$	0.33	0.34	12.2	1.9$^{\#}$	14.2$^{\$}$	13.1	7.5
RC Maniphou 10	50.1	8.7$^{\#}$	1.46$^{\#}$	0.35$^{\#}$	0.40$^{\#}$	12.7	1.4	14.4$^{\$}$	20.3$^{\#}$	7.5
RC Maniphou 11	49.3	6.6	1.21	0.42	0.42	9.3	1.2	14.6$^{\$}$	6.4	6.2
RC Maniphou 12	57.3	8.4$^{\#}$	1.41$^{\#}$	0.36$^{\#}$	0.46	11.7	1.9$^{\#}$	13.7$^{\$}$	22.7$^{\#}$	8.0
Daramphou	68.7$^{\#}$	4.8	0.80	0.31	0.41$^{\#}$	9.3	0.4	10.4	16.0	5.7
SEm±	2.37	0.23	0.07	0.02	0.01	1.95	0.12	0.35	1.03	
LSD (p = 0.05)	7.3	0.7	0.20	0.05	0.03	NS	0.4	1.1	3.2	

NS, not significant at p = 0.05.$^{\#\text{ and }\$}$ indicates the values are statistically at par with each other.

tested (Table 2). The highest (144 cm) and lowest (78 cm) plant height were recorded in Daramphou and RC Maniphou 12, respectively. The highest number of effective tillers per plant (17.5), panicle length (24.5 cm) and harvest index (42%) were observed in RC Maniphou – 7 over the other varieties and control under the study. However, in the case of 1000 grain weight, the highest (33.7 g) and lowest (27.9) values were recorded in RC Maniphou 12 and RC Maniphou 11, respectively. This might be due to genetic makeup as well as effect of favourable environment on the paddy varieties under the study. As plant height is an important morphological character because of its relationships with light interception efficiency, lodging and dry matter accumulation. The number of effective tillers per plant is also important for higher productivity, because more number of effective tillers results more the numbers of panicle per unit area. Significant variation in number of effective tillers per plant, number of grains per panicle, grain size might result significant variation in rice grain yield.

Yield

Grain and straw yield of rice varied significantly (p=0.05) among the varieties (Table 2). The highest grain and straw yield was recorded in RC Maniphou 7 (5.3 t ha^{-1} and 7.8 t ha^{-1}), which was statistically at par with RC Maniphou 11 (5.2 and 7.8 t ha^{-1}, respectively). These two varieties resulted in 81 and 79% higher grain yield, over the local variety, Dharamphou. Higher grain yield in the above mentioned varieties are due to higher values in one or more yield attribute(s), such as number of effective tillers per plant, panicle length, 1000 grain weight and/or harvest index. As varietal evaluation of any crop based on their yield performance is important because yield varied significantly among the varieties when grown under similar environment. The improved rice varieties produced 34 to 83% higher grain yield than Dramphou with the same management practices and performance of RC maniphou 7 and RC Maniphou 11 was better among the improved ones (Table 2). Farmers in the foothills of eastern Himalayan region, India grow mostly traditional cultivars of rice and get only about 1.57 t/ha grain ha^{-1} (http://www.rkmp.co.in) across the growing conditions of lowland and upland including shifting cultivation. Whereas, under lowland condition the average yield ~ 2.0 tha^{-1}, which is much below (<50%) the average yield of improved varieties obtained in this study (4.6 t ha^{-1}). Thus, there is a great potential to increase rice yield in north eastern states of India with adoption of suitable cultivar along with judicious agronomic management practices.

Nutritive quality of rice

Rice is a major source of dietary protein and nutrients for most of the rice growing Asian countries. Rice varieties showed significant (p=0.05) variation in starch and protein content of grain. The local variety Daramphou recorded the highest starch content (68.7%) over the other varieties (Table 3). This might be due to its genetic makeup. Starch content in RC Maniphou

Table 4. Economics and crop profitability of different rice varieties**.**

Treatments	Cost of cultivation (INR)	Gross return (INR)	Net return (INR)	Benefit to cost ratio	Crop profitability (INR ha^{-1} d^{-1})	Market production efficiency (kg ha^{-1} d^{-1})	Biological production efficiency (kg ha^{-1} d^{-1})
RC Maniphou 4	20920	49320	28400	2.4	258	35	90
RC Maniphou 5	20920	51600	30680	2.5	267	36	89
RC Maniphou 6	20920	60600	39680	2.9	317	38	97
RC Maniphou 7	20920	66600	45680	3.2	338	39	97
RC Maniphou 10	20920	61920	41000	3.0	328	39	99
RC Maniphou 11	20920	65520	44600	3.1	337	42	104
RC Maniphou 12	20920	52920	32000	2.5	256	34	84
Daramphou	20920	37440	16520	1.8	122	21	59

4 (67.9%), RC Maniphou 5 (66.4%) and RC Maniphou 7 (63.5%) was comparable with the local variety, Dramphou. All the rice varieties under the study recorded higher protein content over the local one. The highest protein content was recorded in the paddy variety RC Maniphou 7 (8.8%) followed by RC Maniphou 10 (8.7%). The above mentioned two varieties recorded 84 and 82% higher protein content, respectively, over the local variety. Protein, which is a key factor influencing the eating quality of rice varies with the environment and types of soil. The levels of nutrient concentration in grains of rice varieties as observed in the present investigation have also been reported by elsewhere. Both macronutrient (N, P and K) and micronutrient (Cu, Zn and Mn) concentration in grain recorded significant (p=0.05) variations among the rice varieties (Table 3). The lowest values of grain nutrient content were recorded in the local variety, Daramphou. The highest values of grain N (1.47%), P (0.42%), K (0.46%), Fe (18.0 mg kg^{-1}), Cu (2.0 mg kg^{-1}), Zn (17.6 mg kg^{-1}) and Mn (22.7 mg kg^{-1}) were observed in RC Maniphou 7, RC Maniphou 11, RC Maniphou 12, RC Maniphou 5, RC Maniphou 4 and 5, RC Maniphou 5 and RC Maniphou 4, respectively. The QI values of rice grain for human nutrition was significantly high (>7.5) in all the improved varieties with the exception of RC Maniphou 11 (6.2) over the local one (5.7) (Table 3). This might be suitability of the said variety in North Eastern Himalayan.

Economic benefit

All the improved varieties under the study recorded higher net return, benefit to cost ratio, crop profitability, market production efficiency and biological production efficiency over the local variety Daramphou (Table 4).

The highest net return (INR 45,680) and benefit to cost ratio (3.2) was observed in RC Maniphou 7, but RC Maniphou 11 recorded the highest values of crop profitability (357 INR ha^{-1} d^{-1}), market production efficiency (42 kg ha^{-1} d^{-1}) and biological production efficiency (104 kg ha^{-1} d^{-1}). This is due to the fact that RC Maniphou 11 has shorter crop duration (125 days) as compared to RC Maniphou 7 (135 days).

Ranking of varieties

The results of PCA considering yield, QI and benefit cost ratio showed that the highest rank (regression factor score 0.970) was assigned to RC Maniphou 7 (Table 5). This indicates that RC Maniphou 7 is the best among the rice varieties compared followed by RC Maniphou 10, RC Maniphou 11, RC Maniphou 6, RC Maniphou 5, RC Maniphopu 9, RC Maniphou 12 and Daramphou in decreasing order of ranking.

DISCUSSION

The results indicated that yield attributes of rice varieties respond differently under comparable growing conditions (Table 2). Similar values of yield attributes of rice genotypes have also been reported by Ojha (2006, 2010) and Fageria (2004). Plant height is an important morphological character because of its relationships with light interception efficiency, lodging and dry matter accumulation (Fageria et al., 2006). Generally, higher the panicle length higher will be the

Table 5. Screening of the rice varieties through regression factor score.

Treatment	Grain yield (Mg ha^{-1})	Crop quality index	Benefit to cost ratio	Regression factor score	Rank
RC Maniphou 4	3.9	8.1	2.4	-0.351	6
RC Maniphou 5	4.1	8.3	2.5	-0.105	5
RC Maniphou 6	4.8	7.8	2.9	0.556	4
RC Maniphou 7	5.3	7.5	3.2	0.970	1
RC Maniphou 10	4.9	7.5	3.0	0.604	2
RC Maniphou 11	5.2	6.2	3.1	0.602	3
RC Maniphou 12	4.2	8.0	2.5	-0.066	7
Daramphou	2.9	5.7	1.8	-2.210	8
Statistics of variance of PCA					
Eigen value		2.12			
% variance explained		70.59			

number of grain, which ultimately causes higher yield. The number of effective tillers per plant is also important for higher productivity, because more number of effective tillers results more the numbers of panicle per unit area. Ojha (2006) reported that significant variation in number of effective tillers per plant, number of grains per panicle, grain size might result significant variation in rice grain yield. The information on dry matter partitioning to grain (harvest index value) is important in understanding productive capacity of a cultivar (Sheng and Hunt, 1991). Such information should permit better analysis and interpretation of the results and also to better understanding of processes and resources exploitation in crop production (Williams et al., 1996). Based on the observed yield attributing characters RC Maniphou 7 was found to be superior to the other varieties compared. This might be due to better response of this variety over the others under similar agro-ecological situation.

Varietal evaluation of any crop based on their yield performance is important (Baishya et al., 2010), because yield varied significantly among the varieties when grown under similar environment. The improved rice varieties produced 34 to83% higher grain yield than Dramphou with the same management practices and performance of RC maniphou 7 and RC Maniphou 11 was better among the improved ones (Table 2). Farmers in the foothills of eastern Himalayan region, India grow mostly traditional cultivars of rice and get only about 1.57 t grain ha^{-1} (http://www.rkmp.co.in) across the growing conditions of lowland and upland including shifting cultivation. Whereas, under lowland condition the average yield ~ 2.0 t ha^{-1}, which is much below (<50%) the average yield of improved varieties obtained in this study (4.6 t ha^{-1}). Thus, there is a great potential to increase rice yield in north eastern states of India with adoption of suitable cultivar along with judicious agronomic management practices.

Rice is a major source of dietary protein and nutrients for most of the rice growing Asian countries. Protein, which is a key factor influencing the eating quality of rice (Adu-Kwarteng et al., 2003), was considerably high (>7.0%) in all the improved varieties except RC Manipho 11 (6.6) and significantly low in the local variety (4.8%) (Table 3). Reports of such variation in protein content due to varietal influence are not uncommon (Adu-Kwarteng et al., 2003; Perez et al., 1996). A comparison of concentration of seven nutrient elements indicates that all the released varieties are superior in terms of grain nutrient content over the local one. The levels of nutrient concentration in grains of rice varieties as observed in the present investigation have also been reported by elsewhere (Wissuwa et al., 2008; Pooniya and Shivay, 2013). The order of concentration of nutrients across the cultivars was N > K > P > Mn > Zn > Fe > Cu, which is almost similar to that reported by Fageria and Knupp (2013). Among micronutrients, Fe and Zn deficiency occur in both crops and humans (Hotz and Brown, 2004; Sperotto et al., 2010). Rice provides energy to almost half of the world's population and is also a poor source of essential micronutrients particularly Fe and Zn (Bouis and Welch, 2010). Thus, growing rice varieties rich in grain micronutrient content, particularly Fe and Zn, has great potential to mitigate widespread micronutrient deficiencies in humans. Low protein content in grain of RC Maniphou 11 was the cause for its relatively low nutritive value among the improved cultivars. However, based on nutrient (N, P, K, Fe, Cu, Zn and Mn), starch and protein content in grain, the improved cultivars were much superior to the local one for human nutrition and RC Maniphou 4 and 5 were the beast among the improved ones.

Considering yield performance, nutritive quality of grain and economic benefit RC Maniphou 7 was found to be the best among the eight varieties compared followed by RC Maniphou 10, RC Maniphou 11, RC Maniphou 6, RC Maniphou 12, RC Maniphou 5, RC Maniphou 4 and Daramphou in deceasing order of superiority (Table 5). Therefore, from yield, quality and profitability point of view farmers of this region have a choice to select one improved variety instead of growing traditional one. For obtaining higher yield and monetary benefit they can grow any one of RC Maniphou 7, RC Maniphou 10 and RC Maniphou 11. However, if anyone is concern about nutritive value, he can opt for either RC Maniphou 4 or RC Maniphou 5, which give > 40% higher grain yield than the local variety.

Conclusions

Significant differences were obtained among the eight rice varieties for all the parameters compared. Yield, nutritive quality and profitability were better in the improved cultivars than the local one. This is obvious because breeding efforts are made towards attaining food and nutritional security through development of improved crop varieties. Crop improvement also aims to make crop production economically viable. The results of this study prove superiority of RC Maniphou 7 and other improved varieties over the local cultivar in foothills of eastern Himalayan region.

Conflict of Interest

The authors have not declared any conflict of interest.

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