Evaluation of Green Super Rice (*Oryza sativa* L.) Varieties at ARDC Samtenling

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ABSTRACT

The GSR varieties are designed for low input production systems of rice under changing climate which are suitable to southern Bhutan where low input rice production under rain-fed condition is widespread. Forty GSR varieties for rain-fed condition were introduced from IRRI and were evaluated following standard variety evaluation system of field crops in Bhutan at ARDC Samtenling from 2013 to 2017. Six lines were selected and advanced as best GSR varieties from evaluation over five years. In 2018, an experiment was conducted to evaluate six selected GSR varieties in RCBD with three replications. Bhur Kambja1 – a popular rain-fed variety was used as local check. Results show that there was no significant differences in the grain yield between the test entries although IR 83142-B-60-B showed highest yield of 4.20 MTha^{-1}. The statistical analysis of yield components also showed no significant differences in the number of productive tillers, number of grains per panicle and days to 50% flowering. However, there was significant variation in panicle length, 1000-grain weight and plant height of the test entries. IR 83142-B-61-B had longest panicle length (24 cm) while Mahsuri had the highest TGW (23.4 gm) among all the test entries. The comparison of length-breadth ratio of grains also showed significant difference between the test entries with all test varieties being slender except Mahsuri which had medium sized grains. There was no significant difference in the maturity period as 50% flowering days of all entries ranged from 95 to 97 days. All the varieties showed consistent yield performance over the years.

Keywords: *Green Super Rice, Rain-fed ecology, Grain yield, Yield component*

1. Introduction

Rice is one of the most important grains in the world grown by 144 million farm families which makes 25% of world farmers (IRRI, 2016). It is also the most important food for Bhutanese people who derive more than half of their calorie needs from it (Chhogyel, Ghimiray, Gyem, & Dorji, 2016). In 2017, Bhutan produced 86,385 metric tons of paddy from the total harvested area of 51,368 acres (RSD, 2017) with national average yield of 1.6 MT ha^{-1}. Since rice is the most important staple crop in Bhutan the Ministry of Agriculture and Forests (MoAF) gives top priority in increasing paddy production through various means of vertical and horizontal expansion of area and productivity.

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Agriculture Research and Development Centre (ARDC), Samtenling is involved in evaluation of improved varieties through introduction and promotion in lowland paddy production zones of Bhutan and has so far released five improved varieties. An economic impact assessment of rice research program in Bhutan (Shrestha, 2004) reported that despite having 40% share of rice area, the low altitude zone has contributed only 29% of the increase in rice production. The factors attributed are low yield and low adoption of improved varieties in the region. The low altitude paddy growing areas have potential to make significant contribution to national paddy production through adoption of improved, resistant, and high yielding paddy varieties like GSR (Green Super Rice) varieties. The overall adoption rate of improved varieties in the country is 42% (Ghimiray, 2012) which can be increased through introduction and evaluation of GSR varieties. The research center conducted evaluation trials on GSR varieties which were introduced in Bhutan through INGER (International Network for Genetic Evaluation of Rice) nurseries in 2012 from the International Rice Research Institute (IRRI). ARDC-Samtenling evaluated 40 GSR varieties for their performance in southern Bhutan.

The breeding programme for GSR is a collaborative project between IRRI and the Chinese Academy of Agricultural Sciences. According to Zhang (2007), GSR varieties require less application of inputs like pesticides, fertilizers and water while still achieving continuous yield increase and quality. GSR resilience breeding involves fast-track evaluation and development of varieties to cater to the needs of the different regions incorporating genetic traits of multiple abiotic and biotic stress tolerance without compromising grain yield and quality. Such GSR varieties can fit well into varied rice ecosystems and under changing climatic conditions (Ali, Xu, Gao, & Fontanilla, 2012). Furthermore, Yorobe Jr et al. (2016) made important finding of yield benefits of GSR varieties when there is stress like flooding and they equated these varieties to food security in times of extreme climate events.

GSR varieties evaluated at ARDC are lowland rain-fed varieties. According to Mackill (1996) rain-fed lowland rice is usually transplanted, grown in leveled, bunded fields that are shallowly flooded with rain water. Agriculture in Bhutan remains dominated by rain-fed dryland than wetland farming as most of the water sources are dependent on monsoon rainfalls (CIAT, 2017) and most of the low-altitude southern rice belt falls under rain-fed eco-system (Ghimiray et al., 2008). As per Bhutan's climate smart agriculture profile (CIAT, 2017) increasing fallow land in rice cultivation is due to the lack of irrigation water which is one of the emerging threats of climate change. Moreover, 27% of total household farmers (RSD, 2017) have insufficient irrigation water. This signifies the importance of research and evaluation of rain-fed varieties like GSR for paddy production which is equated to food security in the country (Chhogyel, Ghimiray, Wangdue, & Bajgai, 2015).

The present study has three main objectives: (a) to identify best GSR varieties which suit the low input rice production systems of southern Bhutan, (b) to enhance rice productivity of southern Bhutan through release and promotion of superior GSR cultivars and (c) to enhance contribution of Southern Bhutan to national rice production through adoption of GSR varieties.

2. Materials and Method

2.1 Evaluation trial site

The evaluation trial was conducted at Agriculture Research and Development Centre, Samtenling, in Sarpangfrom2013 to 2018 (Figure 1). The site is located at 26^0 54’-26’ N latitude and 90^{0}25’-26’ E longitude. The site falls under wet sub-tropical agro-ecological zone of Bhutan by latitude with an elevation (<600masl), temperature (Max 35^{o}C, Min12^{o}C) and rainfall (2500-5500mm).

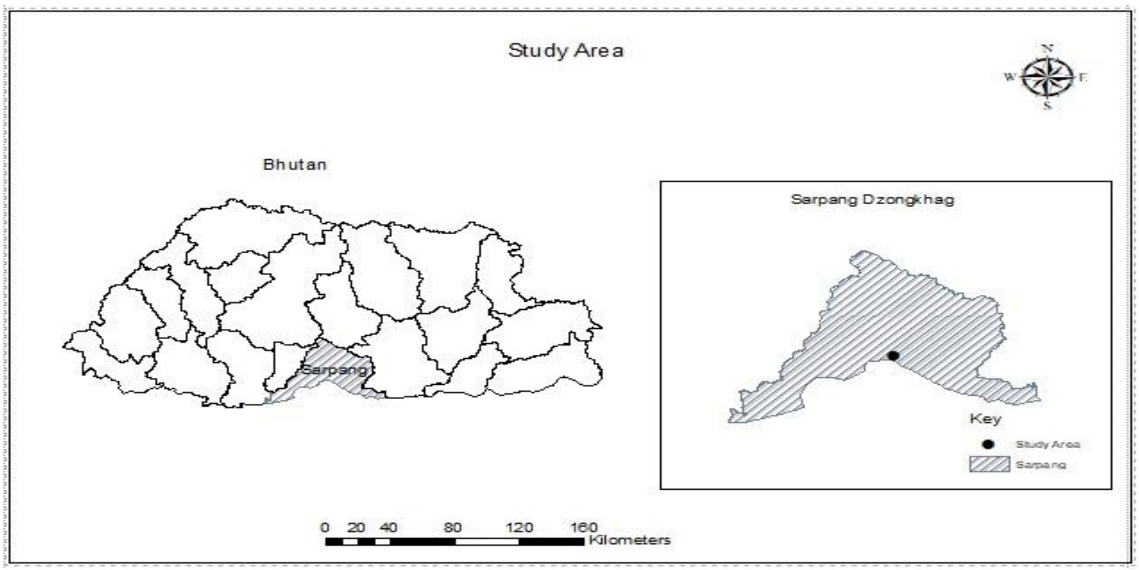

Figure 1. Map of Bhutan showing the study site (ARDC research station) in Sarpang

2.2 Evaluation procedure and methods

The standard variety evaluation system of field crops in Bhutan prescribes evaluation of new materials in Introductory nursery, Observation nursery, Initial Evaluation Trial (IET) and Advanced Evaluation Trials (AET) at research stations. These on-station trials are followed by Pre-production Evaluation Trial (Pre-PET) and Production Evaluation Trial (PET) at farmers’ fields. Introductory nursery was conducted in 2013and Observation nursery in 2014 which were not replicated. Replicated evaluation trials were conducted from 2015(IET), 2016-2017 (AET) using Randomized Complete Block Design (RCBD) with three replications. The data on yield from each replicate was collected and mean yield was calculated. The poor performing lines were discarded in each succeeding year, retaining varieties performing better than the checks. In 2018, as final evaluation in research station, six GSR varieties advanced from various trials were evaluated using RCBD with three replications. A plot size of 10 m^{2}per treatment was used and BhurKambja1 was used as local check. A spacing of 20 x 20 cm was maintained between plants and rows. Fertilizer dose of 70:40:30 NPK kg ha^{-1} was applied. Half the dose of nitrogen was applied as basal along with full doses of phosphorus and potassium. Another half dose of nitrogen was applied in two splits at active tillering and panicle initiation stages. Two hand weedings were performed at 35 DAT and 65 DAT. Additionally, Butachlor @1.5 a.i. ha^{-1} was applied to control grasses and sedges in the initial stage of crop. The trial was conducted purely under rain-fed condition.

2.3 Weather

Average rainfall and relative humidity recorded during the paddy season from 2013 to 2018 is given in Tables 1a and 1b.

Table 1a.Rainfall data recorded at experimental site during study (NCHM, 2018)

Year	Rainfall (mm)					
	June	July	August	September	October	November
2013	675.0	841.2	1122.1	728.6	12.4	0.0
2014	675.0	841.2	1122.1	728.6	12.4	0.0
2015	1152.8	785.4	1621.3	757.7	62.6	52.0
2016	872.2	2392.0	340.6	1001.6	322.8	0.0
2017	1075.0	923.7	2077.8	1032.0	127.1	11.0
2018	1081.8	813.2	781.6	1100.4	89.1	16.4

Table 1b.Relative humidity data recorded at experimental site during study (NCHM, 2018)

Year	Relative Humidity (%)					
	June	July	August	September	October	November
2013	82.8	88.3	87.8	84.4	78.7	61.5
2014	87.6	84.3	87.1	86.3	67.4	66.5
2015	92.2	85.0	91.1	87.6	72.0	71.1
2016	91.2	93.0	85.5	90.6	80.0	74.9
2017	90.7	89.8	92.9	92.8	79.3	71.5
2018	91.5	89.9	88.8	90.9	76.8	69.4

2.3. Data collection

Data from the field were gathered following Standard Evaluation System for Rice (SES) (IRRI, 2002). The yield of different varieties was collected till 2017. In 2018, data on basic agronomic traits were collected. The experimental plots were monitored at regular intervals and data for plant height were gathered after flowering while agronomic parameters such as number of productive tillers, number of filled grains per panicle, panicle length and yields were measured during the harvesting stage. Calculation of grain yield was done following the standard formula with grain yield adjusted to 14% moisture level at harvest. The research data were compiled in Microsoft Excel spread sheet and were analyzed using statistical software STAR 2.0.1. Analysis of variance (ANOVA) and comparison of treatment means were done.

3. Result and Discussion

Table 2. Comparison of means on agronomic traits of GSR selected varieties 2018

Variety	50% Flowering days	Tillers $hill^{-1}$	Plant height (cm)	Panicle Length (cm)	L/B Ratio	No. of grains/ panicle (cm)	1000 Grain wt. (g)	Grain yield ($t\ ha^{-1}$)
6527	96.67	9.83	106.00 a	22.10 ab	4.20 a	136	18.80 e	3.85
Bhur Kambja1	97.50	9.17	106.00 a	20.90 b	3.23 c	143	22.03 b	3.44
Hua 564	95.67	10.33	91.67 cd	22.06 b	3.60 b	144	18.90 e	3.17
IR 83142-B-60-B	96.00	10.67	90.22 d	22.13 ab	3.70 b	154	20.00 d	4.20
IR 83142-B-61-B	97.00	9.33	97.42 bc	24.00 a	3.10 c	151	21.00 c	3.96
Mahsuri	97.33	9.67	103.00 ab	22.70 ab	2.40 d	152	23.40 a	3.40
RC 8	97.17	9.67	86.83 d	22.40 ab	3.10 c	148	21.10 c	3.40
P-Value	0.38	0.709 7	0.0000	0.005	0.0000	0.5998	0.0000	0.0872
CV	1.21	16.78	3.96	2.99	2.36	12.13	0.2783	17.01

In columns, means with same letter are not significantly different at 5% P-value

3.1 Effect of GSR varieties on yield components

3.1.1 Plant height

The plant height was measured when the flag leaves were fully expanded at the crop heading stage from the ground to the tip of tallest tiller. There was significant variation in plant height among the entries ranging from 90.22 cm to 106 cm (Table 2). All GSR varieties are shorter than the check variety except 6527 which produced equal height with the check.

Plant height is an important yield component and within certain range, Zhang et al. (2017) found that the plant height is positively correlated to yield in rice. However, lodging problem in tall varieties often reduces yield. According to Yoshida (1981), a short and stiff culm makes the rice plant more lodging resistant and this increased resistance of improved varieties to lodging appears to be the single character most responsible for high yields. However, medium plant height of 105-115 cm was found ideal and acceptable under Bhutanese context (Chhogyel, Lhab & Dorji, 2013) as there is aspect of straw as fodder. Two GSR varieties evaluated showed similar plant height to Bhur Kambja1 which is currently considered as the best improved variety released for the low altitude rice agro-ecosystem (Dendup, Ngawang, & Chhogyel, 2018). Mahsuri and 6527 with plant height 103cm and 106cm respectively should be easily acceptable to the farmers of southern Bhutan based on their height.

3.1.2 Number of productive tillers per hill

Analysis of variance on productive tillers/hill showed no significant differences among the varieties under study. The number of productive tillers ranged from 9.17 to 10.67 per hill which corresponded to Bhur Kambja1 and IR83142-B-60-B respectively. As per the Standard Evaluation System for Rice (IRRI, 2002), Hua 564 and IR 83142-B-60-B showed medium tillering abilitywhile rest of the entries displayed low tillering ability. However,environmental factors can greatly influence the degree of tillering ability.

According to Yoshida (1981), high tillering capacity is desirable for achieving maximum yields in transplanted rice cultivation and further, missing plants due to poor management can be compensated by high tillering varieties. However, as per Peng, Khush and Cassman (1994), too many tillers per hill increases mortality, poorly filled small panicles which reduces the yield, thus, making medium tillering ability varieties desirable. This may be true in the context of southern Bhutan which is evidenced through wide adaptation of Bhur Kambja1 which averages about 9 tillers per hill. All GSR varieties showed statistically similar number of productive tillers with check variety, indicating their acceptability.

3.1.3 1000- grain weight

Data representing 1000-grain weight (Table 2) showed significant variation among the varieties under study conforming to the findings of (Jahan et al., 2018). Mahsuri had highest 1000-grain weight (23.4 g) while 6527 had the lowest (18.8 g) of all test entries. The 1000-grain weight is a stable varietal character because the grain size is rigidly controlled by the size of the hull (Yoshida, 1981). Hence, the significant variation in 1000-grain weight among the entries under evaluation could be attributed as an intrinsic factor which is further reported by Jahan et al. (2018) that the 1000-grain weight variation is due to different length and width of the seed which are partly controlled by genetic make-up of the genotypes.

3.1.4 Number of grains per panicle

Number of grains per panicle showed no significant differences among the entries; however, five of the six GSR entries produced more number of grains per panicle than the check variety. The number of grains per panicle ranged from 136 to 154 per panicle corresponding to 6527 and IR 83142-B-60-B respectively (Table 2). Number of grains per panicle is one of the components for grain yield and it is one of the targets for breeding program to improve rice yield. However, genetic analysis of number of grains per panicle is difficult as it is controlled by multiple genes and influenced by environmental conditions (Sattari et al., 2015).

3.1.5 Panicle length

The analysis of variance for panicle length of different entries showed significant variation (*P=0.005*) among the test entries. IR 83142-B-61-B had the longest panicle (24 cm) while Bhur Kambja1 had the shortest panicle of 21 cm (Table 2). Other entries showed statistically similar length of panicle. Panicle length determines the number of grains it can hold and consequently, rice yield (Huang et al., 2013) which is further stressed by Liu et al. (2016) as determinants of panicle architecture and yield. Panicle length strongly affects grain number, grain density and rice quality (Wang et al., 2019). Therefore, it is a widely assessed trait in yield-related research. Panicle length of all GSR varieties under study showed relatively longer panicle than the check variety which should be acceptable.

3.1.6 Days to 50 % flowering

There was no statistically significant difference in days to 50% flowering which ranged from 95.67 days to 97.50 days corresponding to Hua 564 and Bhur Kambja1 respectively (Table 2). All the varieties under study showed statistically similar days to 50% flowering which indicated similar maturity duration with the check variety. The growth duration of GSR varieties under evaluation should be acceptable to southern farmers of Bhutan as evidenced through wide adoption of Bhur Kambja1 which matures in 110-120 days. IRRI classifies rice varieties as short duration varieties which mature between 100-120 days, medium duration between 120-140 days and long duration at 160 days or more. Based on this classification, all varieties under evaluation are short duration varieties under ARDC Samtenling condition. These early maturing varieties would enhance vegetable production which is undertaken during winter season in southern Bhutan as early maturing varieties allow intensified cropping (Yoshida, 1981). However, the adoption of early maturing varieties should be in a contiguous area to avoid bird damage.

The other advantage of short duration variety is high water-use efficiency (Yoshida, 1981). The short duration varieties which are efficient in water-use are desirable especially under rain-fed ecology. Furthermore, Chhogyel, Ghimiray and Subedi (2018) reported that rice in Bhutan is particularly vulnerable to climate change due to shorter growing period; hence, short duration GSR varieties are desirable. The maturity duration is more important to Bhutan since the crop has to fit within a single growing period (Dendup et al., 2018). Thus, early maturing GSR varieties coupled with other desired traits would contribute to overall paddy production in southern Bhutan under changing climate.

3.1.7 Length-Breadth (L/B) Ratio

The length by breadth ratio of the entries differed significantly among the varieties under study. The highest value of ratio was recorded for 6527 (l/b=4.2) while lowest corresponded to Mahsuri (l/b=2.4). The coefficient of variation for this trait was 2.36% (Table 2). The length and width of a rice grain are important attributes that determine the class of the rice while the ratio of the length and the width is used internationally to describe the shape and class of the variety (IRRI, 2006). Based on IRRI classification, all the test entries are slender except Mahsuri which is medium.

3.2 Grain Yield

3.2.1 Effect of GSR cultivars on grain yield

The statistical analysis didnot show significant difference in terms of yield among the test entries. However, IR 83142-B-60-B showed highest yield of 4.20t ha^{-1} followed by IR 83142-B-61-B of at 3.96 t ha^{-1}. Three GSR varieties performed better than Bhur Kambja1 in terms of yield (Table 2). The lowest grain yield was recorded by Hua 564 with 3.17 t ha^{-1}.

Grain yield in rice is a complex trait which is ultimate expression of its individual components (Rajeshwari & Nadarajan, 2004) while in a specific environment, yield potential is determined by varietal characteristics and climatic variables such as temperature and solar radiation during the growing season. Thus, the yield potential differs based on location and season. The GSR varieties under ARDC Samtenling showed high yield potential as compared to national productivity of 1.6 Mt ha^{-1}. Therefore, GRS varieties have the potential to enhance paddy production in the country.

3.2.2 Grain yield consistency

The yield consistency of GSR varieties and the check variety from 2013 to 2017 is presented in Table 3. Lowest CV for yield was recorded for RC8 (3.57%) which is more stable than other varieties under study. Three varieties RC8, 6527and IR 83142-B-61-B are more consistent in grain yield than the check variety, Bhur kambja1. Mahsuri showed greater variation (CV=31.56%) as the yield in 2013 was comparatively low in comparison to the following years. Despite low yield in the first year (1.43MT ha^{-1}), the variety performed consistently well from 2014 to 2017 with grain yield ranging from (3.20-3.99 MT ha^{-1}). RC8 showed more consistent in grain yield over five years' duration of evaluation. Stability in performance in rice is one of the most desirable prosperities of a genotype to be released as a variety (Joshi, Shrestha, & Bista, 2003). Further, the multi-location trials over the years will validate the yield consistency of GSR varieties under study.

Table 3. Grain yield of six GSR varieties from 2013-2017

Year	Yield t ha^{-1}						
	6527	Hua 564	IR 83142-B-60-B	IR 83142-B-61-B	Mahsuri	RC 8	Bhur Kambja1
2013	4.22	3.82	4.77	4.57	1.43	3.62	3.37
2014	4.01	3.25	4.61	4.01	3.41	3.83	3.82
2015	3.29	2.61	3.12	3.37	3.53	3.62	2.68
2016	3.99	3.78	4.18	3.83	3.99	3.81	3.84
2017	3.37	2.85	4.7	3.38	3.64	3.53	3.29
Mean	3.78	3.26	4.28	3.83	3.20	3.68	3.40
SD*	0.42	0.54	0.69	0.50	1.01	0.13	0.47
CV** (%)	11.07	16.61	16.04	13.01	31.56	3.57	13.96

SD* Standard Deviation, ** Coefficient of Variance

4. Conclusion

The evaluation of Green Super Rice lines at ARDC-Samtenling for last six years showed that GSR varieties have the potential to perform better than existing traditional varieties in wet sub-tropical zone of Bhutan. The GSR varieties are adaptable to low to medium input production system which is prevalent in this region. Based on statistical analysis of variance among the entries, there was no significant variation in terms of number of days to 50% flowering, productive tillers, number of grains per panicle and grain yield. However, there is variation in terms of plant height, panicle length and grain size. The six GSR varieties were selected as elite varieties for southern Bhutan under rain-fed conditions.

However, there is dearth of information on preferences of varieties by the farmers of this region forcing unilateral selection by research station which should not be the case. These entries therefore, shall be evaluated in farmers' field under Pre-production Evaluation Trial and Production Evaluation trial in coming seasons to validate the performance and preferences of farmers. The organoleptic test, grain quality test, yield stability assessment and participatory varietal selection in farmers' field would be done which would provide further selection of these entries.

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References

Ali, J., Xu, J., Gao, Y., & Fontanilla, M. A. V. (2012). *Green Super Rice (GSR) varieties designed for changing climatic conditions*. Paper presented at the Sustaining Excellence in Rice Research, International Rice Research Institute (IRRI), Los Baños (Philippines).

Chhogyel, N., Ghimiray, M., Gyem, L., & Dorji, C. (2016). Morpho-agronomic Evaluation of Rice (*Oryza sativa* L.) Variety IR28 in Wangdue-Punakha Valley. *Bhutan Journal of Natural Resources & Development, 3*(2), 33-41.

Chhogyel, N., Ghimiray, M., & Subedi, K. (2018). Crop suitability modeling for rice under future climate scenario in Bhutan. *Bhutanese Journal of Agriculture, 1*(1), 49-57.

Chhogyel, N., Ghimiray, M., Wangdue, K., & Bajgai, Y. (2015). Enhancing Bhutanese Rice in the Domestic Market through increased Production and Favorable Pricing Regime. *Journal of Bhutan Studies* (32), 26-44.

Chhogyel, N., Lhab, G., & Dorji, C. (2013). Performance evaluation of improved rice varieties at RDC Bajo 9(2013) 25-30. *Journal of Renewable Natural Resources Bhutan, 9*, 25-30.

Chhogyel N, Ghimiray M, Wangdue K & Bajgai Y. 2015. Enhancing Bhutanese Rice in the Domestic Market through increased Production and Favorable Pricing Regime. *Journal of Bhutan Studies.* 32**,** 26-44.

CIAT. (2017). *Climate-Smart Agriculture in Bhutan*. Washington, D.C.: International Center for Tropical Agriculture (CIAT);The World Bank.

Dendup, C., Ngawang, N., & Chhogyel, N. (2018). Effects of different planting methods on rice (*Oryza sativa* L.) crop performance and labor cost comparison. *Bhutanese Journal of Agriculture, 1*(1), 13-22.

Ghimiray, M. (2012). An analysis of rice varietal improvement and adoption rate by farmers in Bhutan. *Journal of Renewable Natural Resources Bhutan, 8*(1), 13-24.

Ghimiray, M., Dorji, K. D., Katwal, T. B., Penjore, U., Dorji, S., Pem, S. (2008). *Rice in Bhutan - A Source Book*. Thimphu: Council for RNR Research of Bhutan (CoRRB). Ministry of Agriculture, Bhutan.

Ghimiray, M., Wangdi, K., & Chettri, G. (2007). *Commodity chain analysis: Rice Bhutan*. Thimphu: Ministry of Agriculture, Royal Government of Bhutan and FAO-Netherlands Partnership Program.

Huang, C., Yang, W., Duan, L., Jiang, N., Chen, G., Xiong, L. (2013). Rice panicle length measuring system based on dual-camera imaging. *Computers and electronics in agriculture, 98*, 158-165.

IRRI. (2002). *Standard Evaluation System for Rice (SES)*. Los Baños (Philippines): International Rice Research Institute (IRRI).

IRRI. (2006). Rice Knowledge Bank. Retrieved from

http://www.knowledgebank.irri.org/ricebreedingcourse/Grain_quality.htm

IRRI. (2012). *Program and Abstracts: Sustaining Excellence in Rice Research*. Los Baños (Philippines): International Rice Research Institute (IRRI).

IRRI. (2013). *Rice Knowledge Bank: Quality Kit Manual*. Los Baños (Philippines): International Rice Research Institute (IRRI).

IRRI. (2016). *Annual Report 2016. Leading Innovations*. Los Baños (Philippines): International Rice Research Institute (IRRI).

Joshi, B. K., Shrestha, K. P., & Bista, S. (2003). *Yield stability analysis of promising rice genetypes in mid hills of Nepal.* Paper presented at the 23rd National Summer Crops Research Workshop, Kathmandu, Nepal.

Liu, E., Liu, Y., Wu, G., Zeng, S., Thi, T., Thu, G. (2016). Identification of a candidate gene for panicle length in rice (*Oryza sativa* L.) via association and linkage analysis. *Frontiers in plant science, 7*, 596.

Mackill, D. J., Coffman, W. R., & Garrity, D. P. (1996). *Rainfed lowland rice improvement.* Los Baños (Philippines): International Rice Research Institute.

NCHM. (2018). *Climate Data Book*. Thimphu: National Centre for Hydrology & Meteorology (NCHM), Royal Government of Bhutan.

Peng, S., Khush, G. S., & Cassman, K. G. (1994). Evolution of the New Plant Ideotype for Increased Yield Potential. In K. G. Cassman (Ed.), *Breaking the Yield Barrier* (pp. 5-20). Los Baños (Philippines): International Rice Research Institute (IRRI).

Jahan, T., Rahman, S. M. M., Rahman, M. M., Haque, M. M., & Khan, M. A. A. (2018). Evaluation of Some Transplanted AUS Rice Genotypes for Morphology, Yield and Disease Incidence. *European Academic Research, 6*(1), 291-302.

Rajeshwari, S., & Nadarajan, N. (2004). Correlation between yield and yield components in rice (*Oryza sativa* L.). *Agric. Sci. Digest, 24*(4), 280-282.

RSD. (2017). *Bhutan RNR statistics 2017*. Thimphu: Renewable Natural Resources Statistic Division (RSD), Ministry of Agriculture and Forests, Royal Government of Bhutan

Sattari, A., Haghighi, Z. J., Nohtani, H., Noorozi, M., Zaeim, A. N., Moradi, K. (2015). A Review of on the Spikelet Number in Rice. *International Journal of Scientific Research in Science and Technology, 1*(5), 222-227.

Shrestha, S. (2004). *An economic impact assessment of the rice research program in Bhutan*. Los Baños (Philippines): International Rice Research Institute.

Wang, X., Liu, G., Wang, Z., Chen, S., Xiao, Y., & Yu, C. (2019). Identification and application of major quantitative trait loci for panicle length in rice (*Oryza sativa*) through single-segment substitution lines. *Plant Breeding, 138*(3), 299-308.

Yorobe Jr, J. M., Ali, J., Pede, V. O., Rejesus, R. M., Velarde, O. P., & Wang, H. (2016). Yield and income effects of rice varieties with tolerance of multiple abiotic stresses: the case of green super rice (GSR) and flooding in the Philippines. *Agricultural Economics, 47*(3), 261-271.

Yoshida, S. (1981). *Fundamentals of rice crop science* Los Baños International Rice Research Institute, Philippines.

Zhang, Q. (2007). Strategies for developing green super rice. *Proceedings of the national Academy of Sciences, 104*(42), 16402-16409.

Zhang, Y., Yu, C., Lin, J., Liu, J., Liu, B., Wang, J. (2017). OsMPH1 regulates plant height and improves grain yield in rice. *PloS one, 12*(7), e0180825.