Asian Journal of Agricultural Extension, Economics & Sociology

39(1): 96-104, 2021; Article no.AJAEES.65239
ISSN: 2320-7027

Impact of Improved Rice Variety on Productivity and Crop Diversity: A Case of Singye Gewog (Block) in Sarpang District of Southern Bhutan

Chezang Dendup[1*], Sonam Dorji[1], Sonam Tshomo[1] and Langa Tshering[1]

[1]Department of Agriculture, Ministry of Agriculture and Forests, Agriculture Research and Development Centre (ARDC), Samtenling, Bhutan.

Authors' contributions

This work was carried out in collaboration among all authors. Author CD designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors SD and LT managed the analyses of the study. Author ST managed the literature searches. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AJAEES/2021/v39i130510
Editor(s):
(1) Dr. Roxana Plesa, University of Petrosani, Romania.
Reviewers:
(1) Jose Antonio de Fátima Esteves, Instituto Agronômico de Campinas, Brazil.
(2) Falusi Bamidele Ayodeji, Federal College of Education (Special), Nigeria.
Complete Peer review History: http://www.sdiarticle4.com/review-history/65239

Original Research Article

Received 25 November 2020
Accepted 01 February 2021
Published 23 February 2021

ABSTRACT

The survey was conducted in 2019 to generate baseline information for rice yield and varietal diversity, involving 54 experienced rice farmers of Singye Gewog (block) under Sarpang Dzongkhag (district) in Southern Bhutan. A total of 9 varieties were found under cultivation, of which 2 and 7 were assessed to be improved varieties and landraces respectively. The mean yield of improved varieties was 1253.2 kg acre^{-1}, whereas landraces yielded 777.1 kg acre^{-1} (P=.006). The chronological varietal diversity revealed that 47.05% of farmer-named varieties were either lost or replaced over 20 years. However, landrace such as Choti Mahsino was popular, covering 24.6% of the rice cultivated area. Further, taste, yield stability, and utility for festivals were the main reasons for perpetuating landraces' cultivation. The study showed the positive impact of improved varieties on productivity while it has narrowed varietal diversity. On the flip side, the current research found that only one improved variety was adopted which shows a need to promote improved varieties, while the improvement of landraces should also be given priority.

**Corresponding author: E-mail: choyangrangdrel@gmail.com;*

Keywords: Variety adoption; diversity; rice yield; landraces; improved varieties.

1. INTRODUCTION

Rice is the world's most important food for some 4 billion people and global rice demand will increase by 25% between 2010 to 2030 [1]. Bhutan, unlike other rice-producing Asian nations, has a small area but rice plays a pivotal role in Bhutanese agriculture. About 25,084 farm households cultivated rice in about 36,670.21 acres of land during the 2018 season in Bhutan [2]. As rice is the main staple grain of the country, attaining rice self-sufficiency has always been the topmost priority in the agricultural policy agenda [2]. However, in 2019, Bhutan imported 114.67 tons of paddy and 84469.73 tons of milled rice which is valued at Bhutanese Ngultrum 1664.6 million [3] pushing the commodity into the top ten list of import from India. This makes it more evident that the country should put even more effort to attain rice self-sufficiency.

The introduction of improved rice varieties started in 1982 in Bhutan with the establishment of the Centre for Agricultural Research and Development (CARD) which is currently renamed as Agriculture Research and Development Centre (ARDC) located at Bajo in central Bhutan. Since then, the Department of Agriculture released 26 improved varieties from 1988 to 2020 [4], of which five varieties were released specifically for southern Bhutan. Eight of the released varieties were locally bred and remaining introduced from partner institutions, such as the International Rice Research Institute (IRRI) in the Philippines. The adoption rate of improved varieties in Bhutan jumped from 35 % in 2004 [5] to 42% in 2013 [6]. Similarly, a case study of improved variety adoption rate in Wangdue-Punakha valley, conducted by [7] reported an average adoption rate of 65 %. Specifically, [6] also found 14% informal adoption of rice varieties from India by the farmers of southern Bhutan. The adoption of infiltrated rice varieties from India due to porous borders is common despite no official release of the variety in the country. There are no updated studies on the adoption of improved rice varieties in the country.

The promotion and development of improved rice varieties in Bhutan like any other rice-growing nations are to increase rice productivity as a vertical development strategy for rice self-sufficiency. Findings by [7] reported an increase of 33% rice productivity through the adoption of improved varieties in Punakha; a rice-producing district in West-Central Bhutan. Similar positive impacts of improved rice varieties on productivity, income, poverty reduction, and food security were reported by [8], [9], and [10]. The fast replacement of cultivars with newer ones allows farmers to exploit genetic gains from plant breeding [11]. However, increased replacement of local landraces by improved varieties enhances the threat of genetic erosion and eventual extinction [12].

The loss of local crop diversity threatens local and global food security [12]. The reduction of rice varietal diversity in Bangladesh due to the adoption of improved varieties was credited to lowered production risk and increased income associated with improved varieties adoption by [13]. However, [14] found no reduction in pre-existing varieties due to the dissemination of improved New Rice for Africa (NERICA) varieties. Further, [15] found that partial replacement of landraces increased genetic diversity as improved varieties are found to contain more diverse alleles with a high proportion. The diversity changes due to the adoption of improved varieties seem spatial and temporal. Even from the viewpoint of climate change impacts, rice areas in Bhutan are projected to undergo a major shift from high suitability to marginal zones [16]. In such a scenario, Bhutan should put greater efforts into increasing the genetic base of crops to adapt to the impacts of future climate.

In Bhutan, [17] reported 28.75% loss of traditional varieties from 1993 to 2013 for six types of cultivated cereals (rice, maize, wheat, barley, buckwheat, millet) considered in the study and loss of 31.75% loss of traditional varieties of rice in particular. While the National Biodiversity Centre (NBC) strives for *ex situ* conservation of traditional varieties through the collection of seeds from different parts of the country, the conservation method has limitations associated with such as lack of genetic adaptation to the changing environment. This is corroborated by [18] who studied the genetic diversity of landraces conserved under two systems (*in situ* and *ex situ*) and found landraces under on-farm conservation to be more genetically diverse. Therefore, *in situ* conservation of traditional varieties is an important complement to ex-situ

[19] to maintain the evolving diversity of rice varieties for the future generation of Bhutan.

The baseline information on yield and varietal diversity of rice is important to plan productivity enhancement and on-farm conservation programs. It will provide the basis for agriculture research organizations of Bhutan to direct their research areas and to make inclusive decisions. This case study, therefore, attempts to establish baseline information on a) improved rice adoption rate in southern Bhutan, b) varietal diversity of rice in low altitude regions and, c) reasons why our farmers continue to grow traditional rice varieties.

2. MATERIALS AND METHODS

A questionnaire-based survey was conducted in Singye Gewog of Sarpang Dzongkhag to assess rice productivity and varietal diversity. The study was undertaken as part of the Evolutionary Plant Breeding (EPB) Project (2019-2022) in collaboration with NBC, Thimphu Bhutan. The questionnaire was developed by the biodiversity officials, rice researchers, and agriculture officials from project sites. Further, the questionnaires for the survey was pre-tested by engaging researchers and extension officers in the study site. Singye Gewog was identified as the EPB project site for the low altitude rice production ecology of southern Bhutan based on paddy cultivation area and farmers engaged in rice farming.

2.1 Survey Site

Singye Gewog is situated 15 km away from the Sarpang Dzongkhag (District). The block is located at an altitude range of 250-750 masl and consists of five Chiwogs (cluster of villages). The Gewog is under wet to humid sub-tropical agro-ecological zones of Bhutan. Rice is cultivated in four Chiwogs of the Gewog with an estimated area of 646.17 acres of wetland. The rice is normally cultivated from May to December coinciding with the monsoon rain.

2.2 Data Collection and Sampling Method

Data used in this study were obtained from a household survey conducted in 2019. Multistage sampling was employed to select Chiwogs, villages, and farm households. In the first stage, four Chiwogs were purposely selected based on areas under rice and the diversity of landraces. In the second stage, all households that were in the Gewog for more than 20 years were selected using the census record maintained at the office of local government. With the help of the Gewog administration and agriculture extension office, heads of households engaged in rice farming who were above 35 or more years old were selected purposely. In the final stage, 54 experienced rice farmers were randomly selected from four Chiwogs. To make the information of landraces in the past as accurately as possible, only respondents who know rice landraces of 20 years ago were selected.

The survey was conducted by the extension officer and researchers from the Field Crops Program of ARDC (Agriculture Research and Development Centre) Samtenling. The compilation of data was carried out using MS-excel while analysis was carried out using SPSS 22.

3. RESULTS AND DISCUSSION

3.1 Characteristics of the Respondents

Four rice-growing villages of Singye are Lhaptshakha, Ngenyul, Sangaythang, and Yarphelling. Most of the households at Lhaptsakha and Yarphelling were new settlements from the eastern part of the country, hence, only natives were selected. The average age of the respondents was 50.4 years. The selection was based on the criterion of farmers' experience in rice farming, hence, only farmers with ages 35 years and above were selected for the study. The average family size and land holdings were 5.7 members/household and 3.7 acres/household respectively. Most of the respondents have not attended school (65%) while only 22% of the respondents received non-formal education (Table 1).

3.2 Farm-level Adoption and Areas under Improved Varieties

The survey found 2 improved varieties and 7 traditional varieties grown by the respondents in 86.4 acres of land in 2018. Despite the official release of 5 varieties for southern Bhutan (Table 2a) and attempt to promote these varieties in the Gewog, only one (Bhur Kambja 1) was under cultivation at Singye Gewog. The other improved variety was from the Indian state of Assam called Ranjit. 25 farmers and 30 farmers were found growing two improved varieties corresponding to Bhur Kambja1 and Ranjit respectively. The total area under improved varieties was 61.34 acres,

which was more than double of the total area under 7 landraces combined (25.56 acres). Thus, the overall adoption of improved varieties in the Gewog was 70.6%. However, the extend of adoption of varieties gives the overall picture of farmers' preference for the variety like Ranjit which is not released officially in Bhutan but covers the highest area (Table 2b). Choti Mahsino appeared as the most popular landrace cultivated by the farmers of Singye and covers 24.6% of the total cultivated areas of 54 farmers.

Education, land size, and availability of improved variety seeds were found to have a positive influence on adoption [9] which may be the case under this study. Average land holding was found to be 3.3 acres and 38% of the respondents have not attended any formal or non-formal education which may be the factor attributed to the adoption of only two improved varieties. National Seed Center under the Department of Agriculture is the only institute that multiplies and formally distributes improved rice varieties in the country and non-availability may be another factor. The adoption of Ranjit may be due to the availability of its seed in neighbouring border towns of Assam. Farmers who acquire their seeds from neighboring farmers are found more likely to adopt improved varieties [13] which might be the case of adoption of Assam variety like Ranjit in Southern Bhutan as there is informal in-flow of rice seeds from India.

Ranjit is a rainfed variety released by Assam Agricultural University in 1994 while Bhur Kambja1 is a widely adopted variety in southern Bhutan [20] which was released for upland and rainfed ecology. Adoption of these varieties with common ecological adaptation (rainfed) depicts another important factor for adoption; irrigation. The study on factors affecting rice varietal adoption by [21] asserted that hydrology of the environment to be one of the most important factors. Thus, the adoption of rainfed varieties for Gewog like Singye with many places without assured irrigation is justifiable. The future release of rice varieties in Bhutan and wider spread of released varieties, therefore, will be dependent on the development of new varieties that are specifically adapted to various rice production ecology of Bhutan. For high adoption of improved varieties, institutes involved in the development of varieties should give priority to farmers' desired traits, such as resistance to environmental stresses and preferred qualitative rice properties, rather than solely considering increased yield [22]. That gap may be the factor for the non-adoption of other improved varieties released for southern Bhutan.

According to [7], higher yield, resistance to biotic stresses, and availability of seeds and extension services as the reasons for adopting improved rice varieties in mid-altitude rice production areas. Adoption of only Bhur Kambja 1 might be affected by these reasons which need further validation and study.

3.3 Productivity of Improved Varieties and Landraces

The yield data from farmers were collect in terms of their local unit called *Muri* (which is about 40 kgs) and converted to kg acre^{-1}. The average yield of improved varieties as per the data recorded from farmers interviewed was 1253.2 kg acre^{-1} while that of landraces was 777.1 kg acre^{-1} (Table 3). The blunt gap of 476.1 kg acre^{-1} exists between improved varieties and landraces. Farmers adopting improved varieties are found to have a yield advantage over landraces which is a 37.9% gain in comparison to non-adopters. Similar yield gains of improved varieties were also reported by [23,10], and [24]. In Bhutan, findings by [7] reported a yield gain of 33% through the adoption of improved rice varieties in central Bhutan.

Table 1. Socio-demographic information of respondents

Socio-demography	Lhaptsakha (n=6)	Ngenyul (n=24)	Sangaythang (n=19)	Yarphelling (n=5)	All (n=54, Male=30, Female=24)
Average age (years)	44.1	54.4	53.7	49.2	50.4
Average Family size (No.)	6.5	5.2	4.5	6.6	5.7
Average Land holding (acre)	3.6	2.6	3.6	5	3.7
Education (%)					
a) No education	50	75	74	60	65
b) Non-formal education	33	0	16	40	22
c) Primary	17	17	11	0	11
d) High school	0	8	0	0	2

Table 2a. Improved varieties released for southern Bhutan

Variety	Yield potential (t/ac)	Recommended Agro-ecology (MASL)	Year of release
Bhur Ray Kaap 1	2-3	<700	2010
Bhur Ray Kaap 2	1-2	<700	2010
Bhur Kambja 1	1-1.5	<700	2010
Bhur Kambja2	1-1.5	<700	2010
Sokha Rey 1	1-1.5	200-800	2019

Source: [4]

Table 2b. Rice varieties under cultivation at the study site

Variety name	Type	Area (acres)	Average yield (kg/acre)	Number of adopter (nos.)
Bhur Kambja1	Improved	25.84	1248.8	25
Ranjit	Improved	35.5	1257.6	30
Choti Mahsino	Landrace	21.68	781.2	31
Geera sari	Landrace	1	708.5	2
Kalotunay	Landrace	0.5	800	1
Kalo nunia	Landrace	0.13	750	1
Khamtey	Landrace	0.25	750	1
Mama dhan	Landrace	1.2	850	1
Wangdi Karma	Landrace	0.3	800	1

Table 3. Independent t-test for mean yield comparison

Type of variety	Mean yield (kg/ac)
Improved varieties	1253.2a
Landraces	777.1b
Mean yield difference (kg/ac)	476.1
P-value	.006

Means with a similar letter are not significant at 95% confidence interval

Area expansion and irrigation have already become a minimal source of output growth at a world scale [8] and Bhutan challenged by a fragile mountainous ecosystem have a negligible chance for horizontal expansion of rice areas. The rice sector is challenged by shrinking rice areas often losing to urbanization and other infrastructural development. Rice area in 2010 was 56375 acres [25] while it dwindled to 36670.21 acres [2] which accounts for the loss of about 35% of the area to other sectors over a decade in Bhutan. Such a scenario calls for the vertical expansion of rice production and increasing rice productivity is the pillar. Adoption of improved rice varieties as depicted by our survey will add to the national food basket. Hence, improved rice varieties with yield advantage over the landraces are crucial for rice self-sufficiency.

3.4 Rice Varietal Diversity

3.4.1 Farm-level rice varietal diversity

The study found 9 rice varietal richness under cultivation at Singye and more than half of the respondents grow more than one variety of rice in their field. About 3.7% of the respondents represented farmers maintaining the highest varietal diversity with 4 varieties while 13% of the respondents grow 3 different varieties of rice in a season. Around 35.2% of the respondents grow at least 2 different varieties whereas 48.1% were found using only a single variety (Table 3). About 59.1 % accounts for respondents maintaining more than one variety in their field. The study also revealed that 11.1% of the respondents grow only landraces while 42.6% grow only improved varieties.

The strategy of growing more than one variety simultaneously could be in agreement with the factors described in earlier findings such as farmers' farming experience [22], farm agro-ecosystem [26,27], risk consideration, and farmers' participation in the market [28]. Specifically for Bhutan, [7] cited self-consumption, sale, and use for rituals and ceremonies as the factors for growing more than one variety by farmers of central Bhutan. Further, [27] reported the positive role of on-farm diversity

of high altitude rice cultivars on household food security in the mountain agro-ecosystems of Nepal. Household food security may be the reason for maintaining more than one variety of rice at Singye Gewog as well.

One prominent explanation for farmers adopting few landraces despite low yield could be their attachment with the variety over a longer period. They master the art of production and processing of the particular variety they engage in over the years. The popularity of landrace like Choti Mahsino could be attributed to the role it plays for festivals like *Dashain* and *Tihar* which are celebrated with a rice-based dish called *Sel Roti* (ring-shaped rice bread) in southern Bhutan. *Sel Roti* is also popular in southern Bhutan for ceremonies like marriages. Traits of landraces for this may be the driver for on-farm rice varietal diversity. Ethnic traditional cultures play a positive influence on rice landrace variety diversity and genetic diversity [18].

Farmers' naming of the rice variety was used as a basis of the diversity for the survey. All the varieties named were recorded and verified with experienced farmers of Singye Gewog. Some varieties appeared to have different names in different villages and hence, the attempt has been made to validate the varieties using knowledge of experienced rice growers. A Possible explanation of the same variety with different names or different variety with the same name reflects intra- and inter- village exchange of seeds and associated information as the case in The Gambia stated by [29]. When asked to name the rice varieties which were grown 20 years ago, farmers named 17 varieties that were screened based on knowledge of experienced farmers. Currently, 9 unique varieties were found under cultivation. The farmer-named varietal loss over 20 years (1998-2018) was found to be 47.05% at Singye Gewog which resonates with varietal loss of 31.75% reported by [17] in the country from 1993 to 2013. Only two landraces named by farmers 20 years ago were found under cultivation now and the rest of the varieties are either lost or under cultivation in other parts of Southern Bhutan.

Replacement of older varieties with superior improved varieties is the common feature of agriculture. With a different set of preferences in different locations, the rate of rice varietal replacement differs. A survey of 9 districts in Bhutan by [17] revealed a low understanding of Bhutanese farmers on conservation of on-farm agro-biodiversity with only 3% of respondents asserting conservation as their objective of diverse cereal cultivation. Household food security and livelihood were found to be the main driver (90%) of their varietal choices. Therefore, high yielding improved rice varieties with desired preferred traits will always replace the existing landraces or improved varieties under cultivation.

3.4.2 Reasons for growing landraces

The participants were asked the reason they continue to grow landraces despite improved varieties performing well in their villages. 12 pertinent reasons were recorded of which the taste, stable yield, and festival use were prominent with 26%, 20%, and 19% respectively (Fig 1). The taste and value of landraces like Khamtey and Choti Mahsino are well known in low-altitude rice production regions of Bhutan and perhaps, the taste may be the main trait farmers consider in Bhutan. Being an integral part of their culture and tradition, the farmers have developed a special attachment to their landraces [7]. The landraces are also well

Table 4. Maintenance of on-farm varietal diversity

a) No. of varieties grown	No. of respondents	Percentage (%)
4 varieties	2	3.7
3 varieties	7	13.0
2 variety	19	35.2
1 variety	26	48.1
Total	54	100
b) Type of variety grown	**No. respondents**	**Percentage (%)**
Only landraces	6	11.1
Only improved varieties	23	42.6
Both	25	46.3
Total	54	100

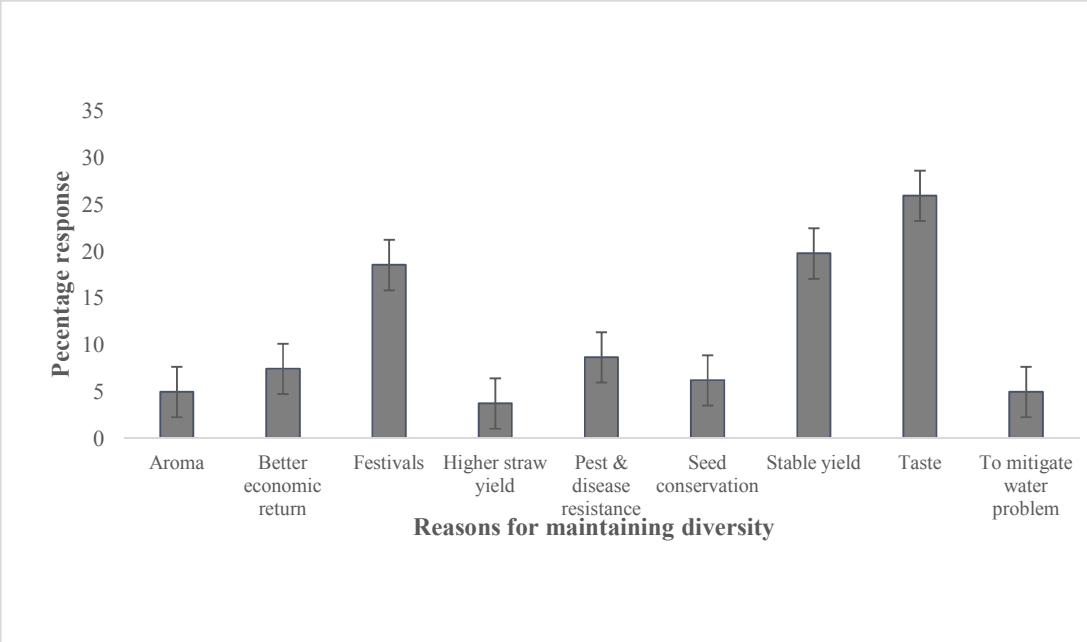

Fig. 1. Farmers' reasons for growing landraces

adapted to their production system over the years with stable yield hence, they value yield stability as reasons for continued cultivation of landraces. In agreement with the findings of [17], farmers of Bhutan hardly regard conservation as the objective of their continued growing of landraces as evidenced through this survey. Only 6% of the respondents regard conservation as a goal for their effort to grow landraces. While aroma and taste credited to be valued much higher than other traits in India [30], the finding from this survey reveals only 5% of preference for the aromatic trait which may be due to the location specificity.

4. CONCLUSION

The study concludes that improved varieties have impacted rice productivity and varietal diversity at Singye Gewog in the Sarpang district. As part of Bhutan's endeavor to increasing rice self-sufficiency, the DoA could continue with the promotion of improved varieties, including Bhur Kambja 1 and Ranjit which are popularly grown by the farmers in the study area. An overwhelming 70.6% of the area is under improved varieties. However, the varietal loss would also require special attention from the development partners and government since biodiversity is also one of the most important areas linked to food production and conservation of natural resources. On-farm conservation plays a vital role in the evolution of species under the threats of future abiotic stresses due to climate change. There is a danger that the landraces could be lost in the process of improved variety promotion, thus, there is a need to safeguard local germplasms for future breeding works. However, the improvement of popular landraces, such as Choti Mahsino, is very crucial for enhancing the yield. This way, it is possible to keep the crop genetic base broad for crop diversification. Bhutan should strive to identify the popular landraces, understand traits preferred by farmers, and initiate improvement of landraces. The process will also ease the impediment like low adoption of improved varieties. Further, a study on determinants of rice varietal adoption is deemed necessary to guide National rice programs and rice researchers of Bhutan.

CONSENT

As per international standard or university standard, Participants' written consent has been collected and preserved by the author(s).

ACKNOWLEDGEMENT

The authors share their gratitude to Evolutionary Plant Breeding Project in Bhutan for financial support for the survey. Mr. Mahesh Ghimary (rice specialist), Mr. Tirtha Katwal (maize specialist),

and Mr. Rinchen Dorji (National Biodiversity Centre) for their inputs in the development of questionnaires. Field Crops Program, ARDC Samtenling for the support in collecting information.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. International Rice Research Institute. Annual report. Race for Impact. Los Baños, Philippines; 2019.
2. Department of Agriculture. RNR census report 2019. Ministry of Agriculture and Forests. Thimphu, Bhutan; 2019.
3. Department of Revenue & Customs. Bhutan trade statistics. Ministry of Finance. Thimphu, Bhutan; 2019.
4. Department of Agriculture. Inventory of released and de-notified crops in Bhutan (1988—2020). Ministry of Agriculture and Forests. Thimphu, Bhutan; 2020.
5. Shrestra S. An economic assessment of the rice research program in Bhutan. Los Baños, Philippines. International Rice Research Intitute. Los Baños, Philippines; 2004.
6. Ghimiray M, Pandey S, Velasco LM. Bhutan report on rice. Country report for the project Tracking of Improved Varieties in South Asia. IRRI monograph. Internation Rice Research Institute. Los Baños, Philippines; 2013.
7. Chhogyel N, Bajgai Y. Modern rice varieties adoption to raise productivity: A case study of two districts in Bhutan. SAARC Journal of Agriculture. 2015;13(2):34—49.
8. Nguezet PMD, Diagne A, Okoruwa VO, Ojehomon V. Impact of improved rice technology (NERICA varieties) on income and poverty among rice farming households in Nigeria: A local average treatment effect (LATE) approach. Quarterly Journal of International Agriculture. 2011;50(3):267—291.
9. Bannor RK, Kumar GAK, Kyeremeh HO, Wongnaa CA. Adoption and impact of modern rice varieties on poverty in Eastern India. Rice Science. 2020;27(1):56—66.
10. Tsinigo E, Yankyerah KO, Fialor SC. Impact of improved rice variety on productivity among smallholder farmers in Ghana. Turkish journal of Agriculture, Food Science and Technology. 2017;5(2): 164—169.
11. Witcombe JR, Khadka K, Puri RR, Khanal NP, Sapkota A, Joshi KD. Adoption of rice varieties- i. age of varieties and pattern of variability. Expl. Agric. Cambridge University. 2016;1—16. DOI:http://dx.doi.org/10.1017/S0014479716000545
12. Chaudhary P, Gauchan D, Rana D, Sthapit BR. Potential loss of rice landraces from a Terai community in Nepal: A case study from Kachora, Bara. Plant Genetic Resources. 2004;137:1—8.
13. Tiongco M, Hossain M. Adoption of modern varieties and rice varietal diversity on household farms in Bangladesh. HarvestPlus Working Paper 22. Washington, D.C: International Food Policy Research Institute (IFPRI); 2015.
14. Barry MB, Diagne A, Sogbossi MJ, Pham JL, Diwara S, Ahmadi N. Recent changes in varietal diversity of rice in Guinea. Plant Genetic Resources: Characterization and Utilization. 2008;1—9.
15. Steele KA, Gyawali S, Joshi KD, Shrestha P, Sthapit BR, Witcombe JR. Has the introduction of modern rice varieties changed ricegenetic diversity in a high-altitude region of Nepal? Field Crops Res; 2009. DOI: 10.1016/j.fcr.2009.04.002
16. Chhogyel N, Kumar L, Bajgai Y, Jayasinghe LS. Prediction of Bhutan's ecological distribution of rice (*Oryza sativa L.*) under the impact of climate change through maximum entropy modeling. Cambridge University Press. 2020;158(1—2):25—37.
17. Katwal TB, Dorji S, Dorji R, Tshering L, Ghimiray M, Chetteri GB, et al. Community perspectives on the on-farm diversity of six major cereals and climate Change in Bhutan. Agriculture. 2015;5:2—16. DOI:10.3390/agriculture5010002
18. Wang Y, Wang Y, Sun X, Caiji Z, Yang J, Cui D, et al. Influence of ethnic traditional cultures on genetic diversity of rice landraces under on-farm conservation in south-west China. Journal of of Ethnobiology and Ethnomedicine. 2016;12:51. DOI: 10.1186/s13002-016-0120-0

19. Zhu Y, Wang Y, Chen H, Lu BR. Conserving traditional rice varieties through management for crop diversity. BioScience. 2003;53(2):158—162.
20. Dendup C, Chhogyel N, Ngawang. Effects of different planting methods on rice (*Oryza sativa* L.) crop performance and cost of production. Bhutanese Journal of Agrculture. 2018;1(1):13—22.
21. Samal P, Pandey S, Kumar GAK, Barah BC. Rice ecosystems & factors affecting varietal adoption in rainfed coastal Orissa: A multivariate probit analysis. Agricultural Economics Research Review. 2011;24:161—167.
22. Thant AA, Teutscherova N, Vazquez E, Kalousova M, Phyo A, Singh RK, et al. On-farm rice diversity and farmers' preferences for varietal attributes in Ayeyarwady Delta, Myanmar. Journal of Crop Improvement. 2020;34(4):549—570. DOI: 10.1080/15427528.2020.11746457
23. Bello LO, Baiyegunhi LJS, Abbeam GD. Productivity impact of improved rice varieties' adoption: Case o smalljolder rice farmers in Nigeria. Economics of Innovation and New Technology; 2020. DOI: 10.1080/10435599.2020.1776488
24. Hossain M, Bose ML, Mustafi BAA. Adoption and productivity impact of modern rice varieties in Bangladesh. The Developing Economies. 2006;44(2): 149—166.
25. Department of Agriculture. Agriculture Statistics 2010. Ministry of agriculture and forests. Thimphu, Bhutan; 2010.
26. Rana RB, Garforth C, Sthapit BR. Farmers' management of rice varietal diversity in mid-hills of Nepal: Implications for on-farm conservation and crop improvement. Plant Genetic Resources: Characterization and Utilization. 2008;1—13. DOI: 10.1017/31479262108048259
27. Gauchan D, Joshi BK, Sthapit S, Jarvis D. Traditional crops for household food security and factors associated with on-farm diversity in the mountains of Nepal. The journal of Agriculture and Environment. 2020;21:31—43.
28. Joshi GR, Bauer S. Determinants of rice variety diversity on household farms in the Terai region of Nepal. Contributed paper prepared for presentation at the International Association of Agricultural Economists Conference, Gold Coast, August 12th -18th; 2006. Available:https://ideas.repec.org/p/ags/iaae06/25422.html
29. Nujten E, Almekinders JM. Mechanisms explaining variety naming by farmers and name consistency of rice varieties in The Gambia. Economic Botany. 2008;62(2):148—168.
30. Pant KP. More profitable rice varieties crowd beneficial landraces out. The journal of Agriculture and Environment. 2010;11:1—9.

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sdiarticle4.com/review-history/65239