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On-farm rice diversity and farmers' preferences for varietal attributes in Ayeyarwady Delta, Myanmar

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ABSTRACT

Myanmar falls within the center of the genetic diversity of many economically important crops, including wild and cultivated rice (*Oryza sativa* L.). However, the majority of the genetic resources of Myanmar, particularly local varieties, and their distribution remain poorly understood. The present study was conducted to investigate the on-farm varietal diversity and the determinants of farmers' variety choices in the Ayeyarwady delta in southern Myanmar, specifically for rainfed rice cultivation. Data from 150 randomly selected households, distributed across five townships, were collected through a semi-structured questionnaire. Households were located in three agro-ecological zones based on the predominant water type (fresh, brackish, and saline). The on-farm diversity appeared to be relatively high according to the number of varieties grown by the farmers. In total, 39 varieties were identified within the survey area. Only 34% of the interviewed farmers grew high-yielding varieties (HYVs) at least on a fraction of their land and the likelihood of adoption of HYVs decreased with length of farming experience, education, and soil fertility, but increased with total area sown under rice according to binomial regression model. From a policy perspective for the high adoption of HYVs, the establishment of a product profile for developing new rice varieties should give priority to farmers' desired attributes and the vital features, such as resistance to environmental stresses or/and preferred qualitative rice properties, rather than solely considering increased yield.

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Agro-ecological zones; high yielding varieties; landraces; Myanmar; *Oryza sativa*

Introduction

Rice (*Oryza sativa* L.) is the staple food of people in Myanmar; it is not only the most important crop for home consumption but also a crop with large export potential. In 2017–2018, paddy-sown area occupied >7.26 million ha, with a production of 28.1 million tons and an average yield of 3.9 t ha^{-1}

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(MoALI 2019). Myanmar has diverse landscapes and geographic variation, ranging from the delta area of the Ayeyarwaddy River in the southern region to the mountainous areas in the northern region. This landscape diversity results in diverse agricultural systems, including deepwater paddy fields in the delta areas, irrigated or rain-fed paddy fields in plain areas and prevailing slash-and-burn agriculture in the mountain areas. Such a geographic diversity, coupled with diverse traditional agricultural systems, contributes to the diversity of crop genetic resources in Myanmar (Garcia et al. 2003; Yi et al. 2008). Nevertheless, the increasing pressure of growing population, together with changing climate, can lead to the substitution of traditional varieties with modern high-yielding varieties (HYVs), with serious implications for the sustainability of rice production.

Local landraces, though usually low yielding, possess wide adaptation ability to local or harsh environmental conditions (Cleveland, Soleri, and Smith 1994) and are considered a reservoir of novel traits, which are invaluable for rice improvement. As the future success of breeding programs depends directly on the amount of available traditional varieties, the conservation of a large number of landraces becomes critical to cope with changing climate and linked future rice cultivation problems, including weather instability, pest infestation, and diseases. Nevertheless, the rate of abandonment of traditional varieties and transition to HYVs are increasing because of market-oriented policy and other factors, which clearly deserve attention (Wale 2012), but the transition drivers remain under-investigated in the study area.

The area of the Ayeyarwady River delta has been considered the largest "rice bowl" in Myanmar since the richness of fertile alluvial soil and abundant monsoon rainfall provide suitable conditions for rice cultivation (Oo et al. 2012). The total paddy area in the Ayeyarwady region covers around 2 million ha, which is 28% of the total cultivated rice area in Myanmar. Nevertheless, this region is highly vulnerable to the impacts of climate change, as evident from frequent salt-water intrusions and flooding. As a result of constant adaptation to stressful conditions, there are unique landraces that have been nurtured and cultivated by the farmers in this region. However, there is little formal documentation on on-farm varietal diversity and farmers' preferences for crop traits, which are needed to guide rice variety development in the Ayeyarwady region.

While in the upper Ayeyarwady region, the HYVs occupy 98% of rice fields because of favorable conditions (Subedi et al. 2017), the proportion of such varieties in the lower delta was only 59%, indicating the importance of the local varieties to counter the harsh environmental conditions in the lower delta region. As the climate change is expected to bring more intense and less predictable precipitations, rice varieties more tolerant to stresses related to extreme weather conditions, including drought and salinity will become necessary not only for farmers but also for rice breeders. The traditional varieties grown mainly under rainfed conditions during the monsoon season could be a valuable source of germplasm for farmers to cope with such constraints. Among the most commonly grown varieties, the Pawsan group, which has aroma, grain quality, and eating quality similar to the reputable aromatic rice varieties of the world, namely *Basmati* of India and Pakistan and *Jasmine* of Thailand, is of special economic importance on the local market (Myint and Napasintuwong 2016).

Based on the importance of the understanding of the drivers of abandonment (and increasing adoption of HYVs) of traditional varieties, this study aims at characterizing and identifying factors that influence farmers' decision to adopt HYVs. In particular, we focus on the assessment of the on-farm varietal diversity and identification of the determinants of farmers' preferences in the rainfed areas in the lower Ayeyarwady delta by analyzing the socio-economic and agro-ecological factors. Information about the factors that affect farmers' variety choice and the impact of their choice on varietal diversity is important not only for programs that are aiming to introduce new modern varieties but also for evidence-based policymaking to develop and implement support measures for targeting and improving access to HYVs. Furthermore, we focus on the desired rice traits, which we link with the selection of traditionally grown varieties in the Ayeyarwady delta region. Although several studies have related varietal traits with the variety selection choices, to the best of our knowledge, this is the first study that compares the farmers' stated cultivation constraints and desired rice properties with the selection of rice varieties grown on the farmers' fields. As the information on the cultivated traditional rice varieties is limited, the farmers' perception of landraces grown and their preferred traits are crucial for the improvement of local agriculture. Therefore, we hypothesize that the agro-ecological region (defined on the basis of the predominant water type), socio-economic characteristics of households, farmers' preferences and problems related to rice cultivation are the key determinants of the adoption of HYVs as well as of the on-farm rice varietal diversity.

Materials and methods

Sites selection and farmers survey

The study area covered five townships: Bogale, Mawlamyinegyun, Labutta, Myaungmya, and Pathein in the lower Ayeyarwady region (Figure 1). We visited key informants, including researchers, township agricultural staff, local leaders, and experienced farmers, to identify the survey areas and select respondents in the five townships in the Ayeyarwady region. In total, 150 respondents were chosen from 15 villages (three villages in each township),

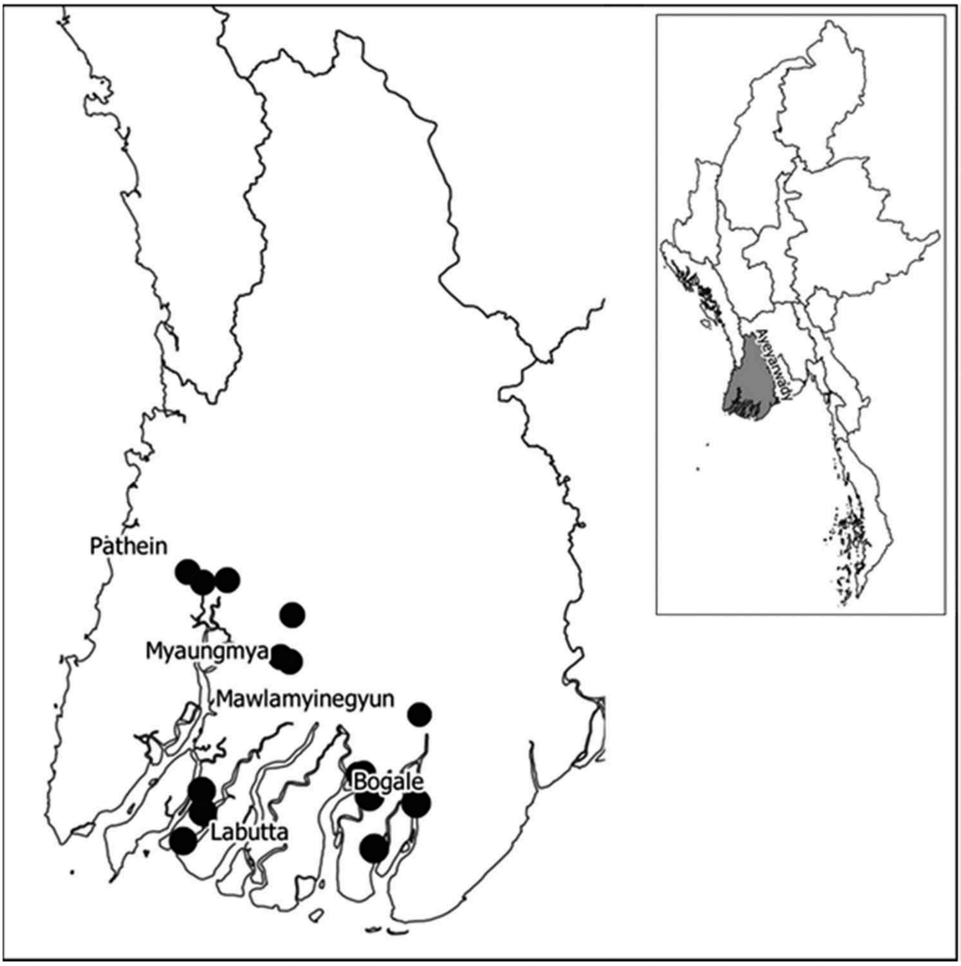

Figure 1. Study area-showing location of surveyed villages in five townships.

representing three agro-ecological zones: i) freshwater zone, where freshwater irrigation allows rice cultivation as a summer crop; ii) saline-water zone, located near coastal areas, where only monsoon rains support paddy growth and iii) brackish-water zone, salt-water interface with freshwater region, where summer crop cultivation is not guaranteed because water salinity levels increase progressively during the dry season.

A structured questionnaire was developed after a thorough literature review and consultation with experts and extension officers. It consisted of several parts to obtain the following information: a) basic household characteristics, b) land-tenure status and soil type, c) rice varieties grown during the monsoon season, d) awareness of the benefits and disadvantages of traditional rice varieties, e) farmers' preferences for rice variety traits, and f) major constraints in rice production.

Farmers were further asked to select the three most important problems related to rice cultivation from a list of 25 potential constraints (3 = the most serious cultivation constraint, 1 = the least important constraint, and 0 if the problem was not considered by the farmer). The problems were classified into three categories: agro-ecological, technical, and socio-economic constraints, and the mean value was calculated for each particular problem, for a category as well as for all study sites. Furthermore, the mean values of each problem were calculated for different agro-ecological zones, different soil-fertility types, terrain, and soil texture to determine the possible effects of these variables on rice cultivation constraints. The mean scores were calculated as a mean of scores given by farmers within a particular agro-ecological zone, soil-fertility type, terrain, and soil texture.

In addition, farmers were asked to score the most appreciated rice properties, with scores ranging from 3 (the most appreciated) to 1 (the least appreciated). The mean score was calculated for each characteristic as well as for a group of characteristics (cultivation characteristics, resistance to stresses and grain characteristics), similar to the rice cultivation constraint scores.

Data analysis

The survey data were processed using SPSS 22 software (IBM SPSS, Inc., Chicago, USA). The effect of each agro-ecological zone, soil fertility, type of terrain, and soil texture on the number of rice varieties grown by the farmers, yield, and area sown was tested using the non-parametric Kruskal–Wallis test ($p < 0.05$), as the parametric test assumptions were not fulfilled. Similarly, Kruskal–Wallis test was used to determine the significance of the effects of different regions (agro-ecological zone, soil fertility, terrain, soil texture) on the scores given to particular cultivation constraints and preferred rice traits because data were not normally distributed.

To assess the impact of the data collected on the use of HYVs, Pawsan or other traditional varieties (scale: 1 = farmers adopting HYVs, 0 = farmers not adopting HYVs, only using traditional varieties), separate binominal logistic regressions were used and the significant models ($p < 0.05$) are presented. We included socio-economic characteristics of households (farming experience, education, land-tenure status, age, total sown area) as well as region and agronomic parameters (agro-ecological zone, soil fertility, type of terrain, soil texture) in the models. Similar binomial logistic regressions were performed to evaluate the impact of the same parameters on the use of more than two rice varieties on the farm (1 = more than two varieties, 0 = less than two varieties, corresponding to farmers growing only one rice variety on their land) to reveal the drivers of crop diversification by the farmers. Binomial logistic regression was also used to analyze the effect of the scores given by the farmers to the different rice traits and cultivation constraints on the adoption of traditional varieties, Pawsan varieties, and HYVs. The power of the model was determined by Nagelkerke R^2, which evaluates the goodness of fit of the logistic regression model.

The correspondence ordination results and the corresponding relationships were projected in the two-dimensional biplot diagrams. Same procedure was used for farmers' preferred rice traits to detect the possible correlation between farmers' preferences and actual varietal choices.

Results

Demographic characteristics of the selected farmers

The average respondents' age was 48 years, with 24 years of experience in rice farming (Table 1). The average number of years of schooling was six, in reference to an education of secondary level. Farmers owned various sizes of farms (0.4 to 81 ha), with the average and median size of landholding being 7.9 ha and 5.3 ha, respectively. Some farmers cultivated rice during both the monsoon and summer seasons, whereas most farmers cultivated only monsoon rice, depending on the agro-ecological region.

Table 1. Physical and socio-economic characteristics of the survey farmers in five selected townships.

	Study sites				
Characteristics	Bogale	Mawlamyinegyun	Labutta	Myaungmya	Pathein
No. of respondents	30	31	30	29	30
Average age (years)	45	47	52	45	51
Education (years)	6	6	6	6	7
Farming experience (years)	20	23	28	23	27
Average sown area (ha)	8.1	5.2	14.5	5.1	6.4
No. of growing cycles (%)					
Two rice cultivations	-	77	-	100	80
One rice cultivation	100	23	100	-	20
Agro-ecological region (%)					
Fresh	-	35	-	31	100
Brackish	-	-	-	69	-
Saline	100	65	100	-	-
Soil texture (%)					
Clay	80	65	90	59	70
Loam	17	29	7	31	20
Sand	3	-	3	3	-
Sandy loam	-	6	-	7	10
Soil fertility (%)					
High	23	16	27	28	17
Average	50	77	60	59	70
Low	27	6	13	14	13

The on-farm rice varietal diversity

On average, farmers grew two varieties on their farms during the monsoon season. As shown in Table S1, 83% percent of the interviewed farmers cultivated more than one variety, with the majority of the farmers growing two to four varieties. Thirty-nine different varieties, i.e., nine HYVs and 30 traditional varieties, were identified by the farmer-given names in this survey. A total number of 21, 12, and 27 varieties were observed in fresh, brackish, and saline agro-ecological regions, respectively. The average yields of HYVs, Pawsan varieties and other traditional varieties were 2.8 t ha^{-1}, 2.6 t ha^{-1}, and 2.7 t ha^{-1}, respectively (Table 2). The Pawsan varieties group was the most popular among the farmers and those varieties were grown by all farmers at least on a portion of their land (61% of the survey area was devoted to Pawsan group). The yield of these varieties was influenced by the agro-ecological region and was higher ($p < 0.05$) in the brackish-water zone compared with the fresh-water zone. Farmers were well aware of the advantages of local varieties, namely, good market value, adaptability to harsh weather conditions, good eating quality, resistance to lodging, low production costs, and stable yield (Table S2).

A larger number of rice varieties per farm were used by the farmers in the saline and brackish-water regions compared with the fresh-water region (Table 2) and on soil described as low to medium fertile. Similarly, farmers in the undulated type of terrain usually used more varieties simultaneously compared to farmers in the flat terrain.

The regression model (Table 3), used to explain the use of more rice varieties (more than two) by the socio-economic factors ($\chi 2 = 41.058$, $p < 0.001$), accounted for 32.8% of variability (Nagelkerke R^2) and classified correctly 68% of the cases. Farmers' experience and education, agro-ecological zone, soil fertility and terrain were the main predictors of the use of more than two rice varieties on farmers' fields.

Farmers with longer farming experience and higher education (in number of years) grew more than two rice varieties on their fields when compared to less experienced and less educated farmers. Furthermore, more farmers growing at least two varieties belonged to the saline-water agro-ecological region compared to the fresh and brackish-water regions (Table 3). The use of at least two rice varieties was also more common in the undulated type of terrain and lower fertility soils compared to flatland type and fertile soils, where growing only one rice variety was more common. The average number of varieties per farmer was 2.55, 2.25, and 2.06 in low, medium, and high soil-fertility areas, respectively (Table 2).

Table 2. Number of grown varieties per farmer, total sown area and yields of Pawsan varieties, other traditional varieties and high-yielding varieties.

	Total			High-yielding varieties			Paw San varieties			Traditional varieties[†]		
Variable	No. [‡]	Sown area [§] (ha)	Yield (t ha^{-1})	No.	Sown area (ha)	Yield (t ha^{-1})	No.	Sown area (ha)	Yield (t ha^{-1})	No.	Sown area (ha)	Yield (t ha^{-1})
Agro-ecological zones												
Fresh	2.06b[¶]	5.06b	2.60b	0.46b	1.31b	2.93	1.04a	2.83b	2.43b	0.56b	0.90b	2.72
Brackish	2.10ab	4.92b	3.22a	0.45b	2.40a	3.49	0.65b	1.71b	2.85a	1.00a	0.79b	2.94
Saline	2.41a	9.91a	2.63b	1.11a	0.01 c	2.00	1.29a	6.65a	2.54ab	0.13 c	3.23a	2.69
Soil fertility												
Low fertility	2.55a	7.10	2.61	0.91	0.82	3.21ab	1.14	4.03	2.36	0.50	2.22	2.50
Medium fertility	2.25ab	6.95	2.67	0.79	0.73	2.87b	1.17	4.34	2.56	0.29	1.86	2.74
High fertility	2.06b	9.91	2.85	0.79	0.79	3.78a	0.98	6.26	2.58	0.30	2.84	2.80
Terrain												
Flat	2.09b	6.97b	2.73	0.78	0.36	3.32	1.08	4.56	2.47	0.23	2.02	2.81
Undulated	2.38a	8.13a	2.67	0.82	1.06	3.04	1.15	4.84	2.59	0.40	2.21	2.65
Soil texture												
Clay	2.25	7.74	2.70	0.86	0.55	2.92	1.14	4.88	2.57	0.25	2.29	2.73
Loam	2.32	6.89	2.71	0.65	1.47	3.42	1.10	4.12	2.45	0.58	1.28	2.74
Sand	2.67	21.1	2.29	1.33	1.33	3.11	-	11.87	2.16	0.33	7.83	2.04
Sandy loam	1.86	3.34	2.80	0.43	0.63	3.67	1.00	1.82	2.55	0.43	0.86	2.77

[†]Traditional varieties other than Pawsan group.
[‡]The number of varieties grown per farmer.
[§]The sown area per farmer.
[¶]Different letters indicate differences ($p < 0.05$, Kruskal–Wallis) between subcategories within the same groups of rice varieties.

Table 3. Model using the socioeconomic variables to explain the use of more varieties (more than two) was significant ($\chi2 = 41.058$, $p < 0.001$). The model explained 32.8% (Nagelkerke R^2) of the variance in the use of more (>2) rice varieties and classified correctly the 68% of the cases.

Variable	Coefficient	Standard error	*p-value*
Experience	0.058	0.027	0.031
Agro-ecological zone †			0.008
Brackish	0.831	0.694	0.232
Saline	2.103	0.683	0.002
Age	0.008	0.030	0.796
Education	0.154	0.076	0.044
Total sown area	0.016	0.019	0.414
Soil texture ‡			0.244
Loam	0.848	0.504	0.117
Sand	0.264	1.346	0.845
Sandy loam	−1.502	1.315	0.253
Soil fertility §			0.006
High	−2.323	0.752	0.002
Medium	−1.807	0.635	0.004
Terrain	1.121	0.427	0.009
No. of cultivation cycles	−0.852	0.619	0.168
Constant	−3.507	1.450	0.016

†Brackish and saline agro-ecological regions were compared to freshwater region.
‡Loam, sand, and sandy loam texture was compared to clay texture.
§High- and medium-fertility soils were compared to low-fertility soils.

The adoption of high-yielding varieties

Nine HYVs were identified; however, the percentage of the farmers growing these varieties was low in the saline-water regions (0.1%), whereas 27.8% and 48.8% of the land was under HYVs in the fresh and brackish-water regions, respectively. The most commonly reported HYVs across all agro-ecological zones were Ayeyarpadaethar, Shwe War Yin, Manawthukha, and Thee Htat Yin (Table S3).

The likeliness of the farmers to adopt HYVs was evaluated using the logit model, with socio-economic characteristics used to describe the use of HYVs at least on some part of the agricultural land. The significant model ($\chi^2 = 78.572$, $p < 0.001$) classified correctly 90% of the cases and explained 62% of variability (Negelkerke R^2), with farming experience, agro-ecological zone, education, total sown area, and soil fertility being the most pertinent variables of the model (the *p*-values are given in Table 4).

According to the model, farmers with less farming experience and less education were more likely to adopt HYVs. The probability of the farmers adopting HYVs also increased with an increase in the total rice area per farmer (Table 4). Furthermore, farmers, who had classified the fertility of the soil as low, were more likely to use HYVs at least on part of their land. The yields of HYVs were the highest on the soils classified as “high fertility soils” but did not follow a linear trend with decreasing soil fertility.

Table 4. Model using the socioeconomic variables to explain the use or not of HYV (the adoption likeliness) was significant ($\chi^2 = 78.572$, $p < 0.001$). The model explained 62.0% (Nagelkerke R^2) of the variance in the selection of HYV and classified correctly the 90% of the cases.

Variable	Coefficient	Standard error	*p-value*
Experience	−0.067	0.037	0.068
No. of cropping cycles	−1.036	1.338	0.439
Family members	0.027	0.221	0.903
Agro-ecological zone †			0.002
Brackish	1.529	0.725	0.035
Saline	−4.995	1.753	0.004
Age	0.058	0.042	0.167
Education	0.198	0.110	0.072
Total sown area	0.078	0.037	0.034
Soil texture ‡			0.365
Loam	0.802	0.654	0.220
Sand	0.930	2.182	0.670
Sandy loam	−1.524	1.370	0.266
Soil fertility §			0.074
High	−2.369	1.166	0.042
Medium	−2.278	1.027	0.027
Terrain	0.133	0.597	0.824
Constant	0.901	2.131	0.672

†Brackish and saline agro-ecological regions were compared to freshwater region.
‡Loam, sand, and sandy loam texture was compared to clay texture.
§High- and mediu-fertility soils were compared to low-fertility soils.

The main cultivation constraints

The main rice cultivation constraints reported by the farmers were grouped into agro-ecological, technical, and socio-economic constraints (Table 5). Mean scores for the severity of the rice cultivation constraints given by farmers were calculated and nine problems were identified as the most important: flooding, rainfall during harvest, extreme water conditions, and abnormal weather (agro-ecological constraints); pest infestation, labor scarcity, rodent infestation, and poor germination rate were identified as the main technical rice cultivation constraints, whereas inadequate input was the main socio-economic constraint. The mean score given to each constraint group was 0.159 for agro-ecological constraints, 0.314 for technical problems, and 0.056 for socio-economic problems.

Farmers in the freshwater agro-ecological region perceived flooding as a more important problem limiting rice cultivation (score = 1.180), whereas farmers from the saline region reported flooding less frequently or of less importance (score = 0.550). On the other hand, pest infestation seemed to be the most important constraints in the saline region (score = 1.713) compared with the freshwater regions (score = 1.020). The labor scarcity was severe in the fresh-water region (score = 1.28); however, the significance of labor scarcity was more obvious in the brackish-water region (score = 2.1). Soil fertility did not influence the majority of the problems reported by the

Table 5. The scores of main rice cultivation problems given by the farmers (3 = the most severe, 1 = the least important, 0 = not considered a constraint by the farmer).

		Agro-ecological zone			Soil fertility			Terrain		Soil texture			
	Total	Fresh	Brackish	Saline	High	Medium	Low	Flat	Undulated	Clay	Loam	Sand	Sandy loam
Constraints	(n = 150)	(n = 50)	(n = 20)	(n = 80)	(n = 33)	(n = 95)	(n = 22)	(n = 65)	(n = 85)	(n = 109)	(n = 31)	(n = 3)	(n = 7)
Agro-ecological	0.159	0.198	0.120	0.145	0.155	0.155	0.186	0.154	0.164	0.165	0.132	0.133	0.200
Flooding	0.773A[†]	1.180a[‡]	0.650ab	0.550b	0.848	0.758	0.727	0.754	0.788	0.789	0.710	0.000	1.143
Raining during harvest	0.160BC	0.160	0.200	0.150	0.121	0.168	0.182	0.062	0.235	0.110ab	0.355a	0.333a	0.000b
Separate land	0.007 C	0.000	0.000	0.013	0.000	0.011	0.000	0.000	0.012	0.009	0.000	0.000	0.000
Poor leveling	0.067 C	0.020	0.000	0.113	0.061	0.074	0.045	0.000b	0.118a	0.092	0.000	0.000	0.000
Sea water intrusion	0.067 C	0.000	0.000	0.125	0.152	0.021	0.136	0.046	0.082	0.092	0.000	0.000	0.000
Mudding after flooding	0.013 C	0.000	0.000	0.025	0.000	0.011	0.045	0.015	0.012	0.009	0.032	0.000	0.000
Extreme water conditions	0.107BC	0.060	0.000	0.163	0.030	0.137	0.091	0.154	0.071	0.147	0.000	0.000	0.000
Drought	0.033 C	0.000	0.000	0.063	0.030	0.042	0.000	0.031	0.035	0.046	0.000	0.000	0.000
Lack of water access	0.040 C	0.120	0.000	0.000	0.091	0.032	0.000	0.092	0.000	0.000b	0.000b	0.000b	0.857a
Abnormal weather	0.327B	0.440	0.350	0.250	0.212	0.295	0.636	0.385	0.282	0.358	0.226	1.000	0.000
Technical	0.314	0.258	0.365	0.335	0.264	0.331	0.314	0.322	0.307	0.319	0.310	0.400	0.200
Pest infestation	1.400A	1.020b	1.100ab	1.713a	1.303	1.421	1.455	1.338	1.447	1.358	1.710	2.333	0.286
Labor scarcity	1.233A	1.280ab	2.100a	0.988b	0.727b	1.453a	1.045ab	1.400	1.106	1.312	0.871	1.000	1.714
Rodent infestation	0.147B	0.000b	0.000b	0.275a	0.303ab	0.053b	0.318a	0.231	0.082	0.147	0.129	0.667	0.000
Crab incidence	0.047B	0.060	0.000	0.050	0.091	0.011	0.136	0.015	0.071	0.009	0.194	0.000	0.000
No access to quality seeds	0.047B	0.080	0.000	0.038	0.091	0.032	0.045	0.015	0.071	0.037	0.097	0.000	0.000
Slow growth	0.027B	0.000	0.100	0.025	0.061	0.021	0.000	0.031	0.024	0.037	0.000	0.000	0.000
Poor soil quality	0.080B	0.100	0.100	0.063	0.000	0.105	0.091	0.123	0.047	0.083	0.097	0.000	0.000
Weed problem	0.027B	0.000	0.000	0.050	0.000	0.042	0.000	0.000	0.047	0.037	0.000	0.000	0.000
Poor germination rate	0.120B	0.020	0.250	0.150	0.061	0.158	0.045	0.062	0.165	0.165	0.000	0.000	0.000
Impure seeds	0.007B	0.020	0.000	0.000	0.000	0.011	0.000	0.000	0.012	0.009	0.000	0.000	0.000
Socio-economic	0.056	0.048	0.020	0.070	0.115	0.036	0.054	0.058	0.054	0.055	0.065	0.000	0.057
Inaccessible machinery	0.067	0.080	0.000	0.075	0.182	0.032	0.045	0.092	0.047	0.046	0.097	0.000	0.286
Poor market	0.020	0.000	0.000	0.038	0.030	0.021	0.000	0.015	0.024	0.028	0.000	0.000	0.000
High inputs	0.020	0.000	0.000	0.038	0.091	0.000	0.000	0.046	0.000	0.028	0.000	0.000	0.000
Inadequate credit	0.067	0.040	0.100	0.075	0.061	0.063	0.091	0.062	0.071	0.037	0.194	0.000	0.000
Inadequate inputs	0.107	0.120	0.000	0.125	0.212	0.063	0.136	0.077	0.129	0.138	0.032	0.000	0.000

[†]Different capital letters indicate differences ($p < 0.05$) between given scores within the constraint category (Agro-ecological, technical, and socio-economic constraints).
[‡]Different lower-case letters indicate statistically significant differences ($p < 0.05$, Kruskal–Wallis) between scores given by the farmers in different regions within the main four categories (Agro-ecological zone, soil fertility, terrain, soil texture). No letters indicate no statistically significant differences within the category.

farmers, except for labor scarcity and rodent infestation (Table 5). Logically, only farmers in the undulated type of terrain reported poor leveling as a significant problem (score = 0.118). Farmers who cultivated on sandy loam soils did not report rainfall during harvest as a constraint (unlike farmers who cultivated other soil types) but identified the lack of access to water as a constraint limiting rice cultivation (score = 0.857).

Additionally, cultivation problems reported by the farmers were used to explain the selection of rice varieties, but no significant logistic regression model was found. On the other hand, the correspondence analysis (Figure 2(a)) of nine most important cultivation constraints (scores>0.1) and rice varieties revealed a relationship between both variables (χ^2 = 397.289, p = 0.002). No correlation between problems and the adoption of HYVs or Pawsan group varieties was found, and only the use of other traditional varieties (Figure 2(b)) seemed to be influenced by the cultivation problems reported by the farmers (χ^2 = 186.127, p = 0.077).

Rice characteristics valued by farmers

Farmers gave a score of 2.504, 2.394, and 2.621, respectively, to production characteristics, resistance to stress and grain characteristics (Table 6). Within the production characteristics, low production costs (2.947), high yield (2.900), resistance to grain shattering (2.900) and resistance to lodging (2.860) were the most appreciated rice traits. Resistance to insects (2.893) and resistance to diseases (2.893) were the most important traits among the characteristics linked to the resistance to stress. Among grain characteristics, high market demand for specific rice grains scored the highest among the traits (3.000), followed by high milling recovery (2.933), low amount of

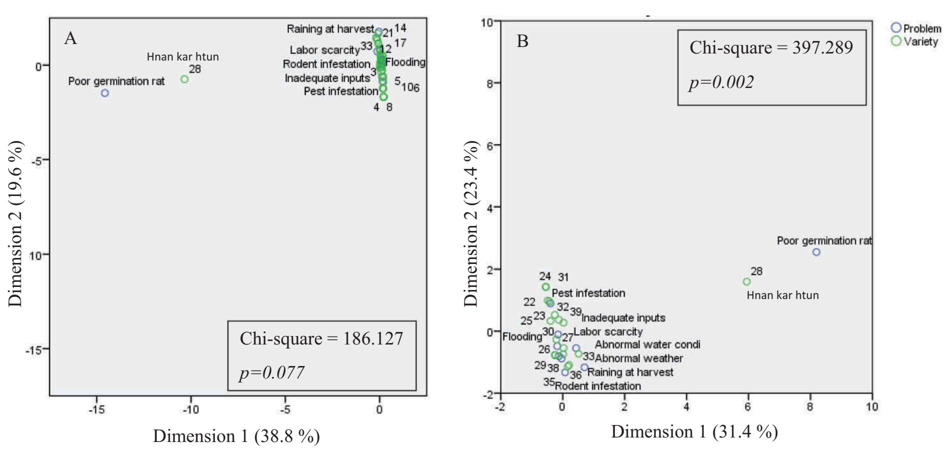

Figure 2. Correspondence analysis (CA) of nine main rice cultivation problems and all cultivated varieties (n = 39) (a) and traditional varieties others than Pawsan group rice (n = 20) (b).

Table 6. The scores of the rice traits given by the farmers (3 = the most appreciated, 1 = the least appreciated).

		Agro-ecological zone			Soil fertility			Terrain		Soil texture			
	Total	Fresh	Brackish	Saline	High	Medium	Low	Flat	Undulated	Clay	Loam	Sand	Sandy loam
Rice traits	(n = 150)	(n = 50)	(n = 20)	(n = 80)	(n = 33)	(n = 95)	(n = 22)	(n = 65)	(n = 85)	(n = 109)	(n = 31)	(n = 3)	(n = 7)
Production characteristics	2.504	2.520	2.486	2.498	2.468	2.510	2.532	2.486	2.518	2.509	2.461	2.571	2.592
High yield	2.900A[†]	2.960	2.850	2.875	2.909	2.884	2.955	2.908	2.894	2.890	2.903	3.000	3.000
Low production costs	2.947A	2.960	2.900	2.950	2.939	2.947	2.955	2.939	2.953	2.936	2.968	3.000	3.000
High straw production	1.413D	1.380	1.600	1.388	1.303	1.411	1.591	1.385	1.435	1.431	1.258	1.333	1.857
Short growing period	1.793 C	1.840	1.800	1.763	1.636	1.832	1.864	1.846	1.753	1.752	1.903	2.000	1.857
Resistance to lodging	2.860AB	2.900	2.900	2.825	2.879	2.842	2.909	2.800	2.906	2.881	2.742	3.000	3.000
Resistance to shattering	2.900AB	2.860	2.850	2.938	2.849	2.905	2.955	2.892	2.906	2.917	2.807	3.000	3.000
High tillering ability	2.713B	2.740	2.500	2.750	2.758	2.747	2.500	2.631	2.777	2.752	2.645	2.667	2.429
Resistance to stress	2.394	2.313	2.442	2.433	2.237	2.430	2.477	2.403	2.388	2.401	2.376	2.389	2.381
Resistance to insects	2.893A	2.900	2.900	2.888	2.758b[‡]	2.926ab	2.955a	2.846	2.929	2.890	2.871	3.000	3.000
Resistance to diseases	2.893A	2.900	2.950	2.875	2.788	2.916	2.955	2.862	2.918	2.872	2.936	3.000	3.000
Resistance to drought	2.093 C	1.880	2.200	2.200	1.970	2.105	2.227	2.246	1.977	2.101	2.065	2.333	2.000
Tolerance to flooding	2.540B	2.520	2.550	2.550	2.455	2.558	2.591	2.554	2.529	2.569	2.387	2.667	2.714
Tolerance to salinity	2.200 C	1.980	2.300	2.313	2.091	2.168	2.500	2.169	2.224	2.211	2.226	2.000	2.000
Tolerance to cold injury	1.747D	1.700	1.750	1.775	1.364b	1.905a	1.636ab	1.739	1.753	1.762	1.774	1.333	1.571
Grain characteristics	2.621	2.578	2.595	2.653	2.565	2.633	2.653	2.589	2.645	2.625	2.592	2.879	2.571
High milling recovery	2.933AB	2.940	2.900	2.938	2.970	2.926	2.909	2.923	2.941	2.936	2.968	3.000	2.714
High demand	3.000A	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000	3.000
Softness	2.760B	2.740	2.800	2.763	2.697	2.758	2.864	2.708	2.800	2.780	2.742	3.000	2.429
Short cooking time	1.747D	1.680	1.750	1.788	1.697	1.705	2.000	1.862	1.659	1.651b	1.871ab	2.667a	2.286ab
Taste	2.840AB	2.800	2.850	2.863	2.879	2.863	2.682	2.754b	2.906a	2.853	2.839	3.000	2.571
Aroma	2.733B	2.680	2.700	2.775	2.606	2.790	2.682	2.600b	2.835a	2.762	2.645	3.000	2.571
Stickiness of cooked rice	2.393 C	2.320	2.400	2.438	2.000b	2.463a	2.682a	2.277	2.482	2.431	2.161	3.000	2.571
Longer keeping quality	2.747B	2.680	2.650	2.813	2.788	2.737	2.727	2.646	2.824	2.725	2.807	2.667	2.857
High volume expansion	2.740B	2.640	2.700	2.813	2.849	2.705	2.727	2.708	2.765	2.771a	2.742a	2.667ab	2.286b
Stay longer in stomach	2.000D	1.920	1.850	2.088	1.788	2.074	2.000	2.092	1.929	2.037	1.807	2.667	2.000
Less broken grains	2.933AB	2.960	2.950	2.913	2.939	2.937	2.909	2.908	2.953	2.927	2.936	3.000	3.000

[†]Different capital letters indicate differences ($p < 0.05$) between given scores within the trait category (production characteristics, resistance to stress, grain characteristics).
[‡]Different lower-case letters indicate statistically significant differences ($p < 0.05$, Kruskal–Wallis) between scores given by the farmers in different regions within the main four categories (Agro-ecological zone, soil fertility, terrain, soil texture). No letters indicate no statistically significant differences within the category.

broken grains (2.933) and taste (2.840). The importance of the resistance to insects and of the stickiness of cooked rice increased with decreasing soil fertility, and rice aroma was more valued by the farmers from the undulated areas compared to the farmers from flatlands.

Three regression models were constructed to predict the use of traditional varieties, HYVs and Pawsan group varieties. While no model for the use of HYVs and Pawsan varieties was significant, the use of traditional varieties (other than Pawsan) was positively related to the scores given to resistance to drought, high volume expansion, and the filling value (the characteristic valued by the farmers) ($\chi 2$ = 41.058, p = 0.007) (Table 7). On the other hand, farmers, who placed high values on the low amount of broken grains and the properties of cooked rice with high values, were more likely to adopt HYVs.

Table 7. Model using the rice traits preferred by the farmers to explain the adoption of traditional varieties (other than Pawsan group) was significant (χ^2 = 41.058, p = 0.007). The model explained 34.1% (Nagelkerke R^2) of the variance in the selection of traditional varieties and classified correctly the 75.3% of the cases.

Rice traits	Coefficient	Standard error	*p-value*
Production characteristics			
High yield	−0.285	0.801	0.722
Low production costs	0.355	1.157	0.759
High straw production	0.948	0.969	0.328
Short growing period	0.182	0.590	0.758
Resistance to lodging	−0.842	0.814	0.301
Resistance to shattering	0.710	0.925	0.443
High tillering	−0.214	0.520	0.681
Resistance to stress			
Resistance to insects	−0.812	1.389	0.559
Resistance to diseases	0.073	1.395	0.958
Resistance to drought	0.824	0.486	0.090
Tolerance to flooding	0.457	0.475	0.336
Tolerance to salinity	−1.156	0.501	0.021
Tolerance to cold injury	0.487	0.604	0.420
Grain characteristics			
High milling recovery	0.152	0.891	0.865
Softness	−0.429	0.517	0.407
Short cooking time	0.806	0.591	0.173
Taste	0.123	0.731	0.867
Aroma	0.615	0.625	0.325
Stickiness of cooked rice	−0.641	0.461	0.164
Longer keeping quality	−1.320	0.620	0.033
High volume expansion	2.168	0.578	0.000
Stay longer in stomach	1.113	0.493	0.024
Less broken grains	−1.198	1.175	0.092
Constant	1.876	1.806	0.299

Discussion

Rice varietal diversity

Eighty-three percent of the interviewed farmers cultivated more than one variety during the monsoon season. Growing several varieties per season could be a strategy to address diverse weather conditions (Subedi et al. 2017). The on-farm diversity was relatively high as 39 different rice varieties were cultivated: nine of them were HYVs, 10 were from the Pawsan group and 20 were traditional varieties (other than Pawsan).

The number of farmers simultaneously growing more rice varieties was positively affected by farmers' experience and education, which suggests that farmers' decision to increase rice varietal diversity was a factor of cumulative outcome of farmers' choices during the past years. Similarly, farmers located in areas less suitable for rice cultivation, such as saline-water agro-ecological region or undulated type of terrain, were more likely to grow more varieties (especially traditional ones) compared to farmers in the brackish or fresh-water regions and flatlands. Similar trend was observed for the farmers who reported their soil as non-fertile, as they tended to adopt more rice varieties on their farms. These findings indicated that growing more than one variety was farmers' strategy to secure rice production and decrease the risk of crop failure in areas less suitable for rice cultivation and in areas more prone to risks related to harsh environmental conditions (i.e., saline-water intrusion, soil erosion in hilly areas). Furthermore, as the terrain and soil fertility of such areas are likely more diverse compared with flatlands, farmers adapt by dividing their fields into smaller portions and by sowing different varieties in particular areas on their farms.

Farmer's reliance on local traditional varieties because of their adaptability to local conditions and to environmental stresses is a well-accepted fact. In agreement with previous results (Cleveland, Soleri, and Smith 1994), these traits in our study were among the most valued rice characteristics reported by the farmers in the survey area and partly explained (34%) the use of traditional varieties in the regression model. In particular, farmers, who considered resistance to drought, tolerance to salinity, and several rice grain traits to be important, were the ones that preferentially used traditional varieties (other than Pawsan group); traditional varieties generally show little improvement when high amounts of fertilizers are applied (Yi et al. 2005).

Local varieties, particularly the aromatic Pawsan varieties, were considered to be of high importance in the Ayeyarwady delta region (occupying 61% of total cultivated land) and were valued mainly for their high market price and demand, grain texture, aroma and flavor and relatively good yield (2.62 t ha^{-1}). Many different sub-selections from the original landrace "Pawsan Hmwe," a strongly photosensitive variety, which cannot flower beyond a critical photoperiod, were identified in the delta. Pawsan Bay Kyar and

Pawsan Yin, which are only slightly photosensitive, were farmers' selections from Pawsan Hmwe, as they could flower under any length of photoperiod (Subedi et al. 2017). Manaw, Hnan Kar, and Madama were photoperiod-sensitive varieties, with higher yield (3 t ha^{-1}) compared to the Pawsan group (Table S3). Farmers, whose fields were located in the lowland areas, usually grew these varieties because of their tolerance to submergence. Moreover, the landrace Hnan Kar was resistant to nematode (*Ditylenchus angustus*) attacks, rice blast disease (*Magnaporthe oryzae*) and rice stem borer (*Scirpophaga incertulas*). Nevertheless, farmers, who reported pest and disease attacks, did not seem to select these varieties specifically, either because they did not have access to the seeds or because of the lack of knowledge of the advantages of particular rice varieties. Similarly, no conclusions could be drawn from the farmers' preferences for rice characteristics because of the adoption of Pawsan group varieties by almost all farmers in the study area; therefore, their adoption could not be described by the selected logit model.

Socio-economic and agronomic factors to determine the adoption of HYVs

Farmers predominantly preferred traditional varieties to HYVs in the study area, with only 34% of interviewed farmers growing HYVs. Despite the higher yields, farmers in the survey area adopted fewer HYVs compared to Pawsan and traditional variety groups, which indicated that traits other than yield were important in their decision-making. While Khanal, Adhikari, and Wilson (2017) reported that rice yield was the most important factor influencing farmers' varietal selection, the farmers in the Ayeyarwady region were generally aware that HYVs were less resistant to stresses, unless specially bred varieties were included, which, however, was not the case for the HYVs used by the farmers in the survey area. This clearly indicates that while high yields are desired by the farmers, growing varieties capable of coping with harsh local conditions remains essential and highlights the usefulness of such traditional varieties in breeding programs.

According to the regression model, socio-economic variables and agronomic factors (farming experience, education, total sown area, soil fertility, and water region) had a significant impact on the likeliness of cultivating HYVs. While Islam, Sumelius, and Bäckman (2012) identified farmers' age, experience, irrigation coverage, off-farm income, access to microfinance, and membership in village local groups as the key factors driving the HYVs adoption; we found the likeliness of HYVs adoption to be positively influenced by total area sown to rice, but negatively influenced by farmers' experience and education. The negative impact of farming experience can be explained by a higher awareness of the benefits of the traditional varieties. Furthermore, while HYVs may offer immediate benefit with respect to increased yields, farmers with longer experience could have faced long-term disadvantages of HYVs in increased risks of incidents, including pest or disease attacks or lower tolerance to stresses resulting in production losses (Wale 2012).

The negative relationship between HYVs adoption likeliness and farmers' education is surprising as education is generally related to a more efficient use of inputs and facilitated perception and interpretation of new technologies and new improved varieties. It is well accepted that HYVs are relatively more labor-intensive and have higher input costs when compared to traditional varieties, which may result in reduced adoption of HYVs if a large proportion of family members lives off-farm. Higher education and longer experience also likely influence farmers' capacity to determine the most suitable rice variety based on available resources and may rely more on stable, low-input traditional varieties in the case of the limited access to inputs, such as labor, irrigation, fertilizers, or pesticides, which are often the key determinants of HYVs adoption (Samal et al. 2011). Moreover, since HYVs adoption likeliness decreased with education but increased with total area sown to rice, it could be speculated that more educated farmers had other incomes besides rice cultivation and diversified their portfolio of cash crops.

In addition, new unknown varieties could be considered risky because of the lack of an assured market. On the other hand, Wale (2012) concluded that technology and market, particularly farmers' access to new HYVs, were among the most important drivers related to the abandonment of traditional varieties. As the majority of the farmers in the study area were using their own seeds and did not generally purchase seed, farmers' lack of access to the seeds of modern HYVs could also be the reason for the relatively low adoption of HYVs.

The farmers' perception of the fertility of their fields seemed to influence the likeliness of the adoption of HYVs, as these varieties were more commonly used by those farmers who described their soil fertility as low or medium. As higher subsistence pressure has been indicated as an important driver of HYVs adoption (Hollaway, Shankar, and Rahman 2002), farmers with non-fertile soils likely had, in general, very low rice yields. As the yields of traditionally grown varieties are generally lower compared to HYVs, these farmers may be more eager to experiment with varieties that can guarantee higher yields (HYVs) and thus, higher income. Nevertheless, HYVs perform well only under optimal or near-optimal growing conditions (Bardsley and Thomas 2005) and on fertile soil. Thus, subsistence pressure and low yields can hardly explain the adoption of HYVs, as farmers with knowledge of disadvantages of HYVs, under particular growing conditions, likely corresponding to more educated farmers, are apparently less prone to experiment with HYVs.

The distribution of HYVs was uneven. These varieties were almost absent in the saline-water region, since traditional varieties were more resistant to salinity. Thus, developing new rice varieties, which are tolerant to the major abiotic stresses, such as drought, flooding, salinity, and high temperature, will affect the adoption of HYVs by the farmers located in unfavorable growing environments, especially in saline areas. Therefore, the identified traditional varieties used by local farmers are a valuable source of genetic material required for successful breeding of new improved varieties.

Rice cultivation constraints and the preferred characteristics

From all the 25 rice cultivation constraints identified by the farmers, pest infestation received the highest score. Farmers revealed that the control of pests and diseases incurred high costs while considerably reducing rice productivity and quality. Lack of available labor was identified as a second constraint because young people often migrate to other areas or neighboring countries, where labor wages had risen in the recent years. As a result of these shortages, farmers were unable to plant their paddy crop in a timely manner, ultimately delaying harvest and risking damage to the crops by heavy rains. Consequently, such paddies fail to fetch a satisfactory price on the market. The third constraint, flooding, seriously impacted rice productivity. Large areas of the delta are subject to flooding, ranging in duration from a few days to two or 3 months, presenting significant risks to farmers. Some areas are suitable for deep water rice, a low-yielding rice type that elongates to stay above the rising water. The native deepwater rice is of low palatability and is therefore grown as animal feed in Myanmar (Nguyen and Pittock 2016). Thus, there is a need to develop flood-tolerant rice varieties that also produce high yields and good quality. Without the benefit of submergence tolerance, excessive flooding severely limits the scope of using improved HYVs and crop management (Denning, Baroang, and Sandar 2013).

Nowadays, because of abnormally heavy rain at the rice-ripening stage, farmers encounter crop damage from both plant lodging and shattering of rice grains. Hence, farmers continue to grow local rice varieties, as resistances to shattering and lodging are prominent traits, which were highly scored by the farmers. Tillering ability is a yield-determining characteristic of rice plants. The growth and development of tillers depend partially on environmental factors, such as radiation, temperature, and nutritional conditions, and partially on varietal characteristics (Hanada 1993). Generally, varieties with more tillers have a higher number of panicles and their contribution to yield is higher than that of the low-tillering varieties (Nuruzzaman et al. 2012). Thus, it is not surprising that farmers highly rated tillering ability. On the other hand, especially in areas with harsh environmental conditions or with unpredictable climate, varieties with shortened growing period could be preferred, as the risk of harvest loss is reduced. Surprisingly, a short-growing period was among the least important traits mentioned by the farmers. High straw production was scored as the least important trait because straw is commonly used for animal fodder and bedding; however, cattle or buffalo were not often employed in farming activities.

Because of high production losses attributable to pests and diseases, farmers tend to grow local varieties, which can be tolerant to some extent, while modifying agronomic practices (spacing, adjusting planting time, water management) to reduce pest and disease attacks. Farmers wanted new resistant varieties and new methods of control, including biological control methods. Besides biotic stresses (diseases/insects), the rice crop frequently faces abiotic stresses, such as submergence, salinity, drought, and cold stresses. Excess water is the main constraint to rice productivity in large areas of rainfed lowland ecosystems. This regularly affects some 15–20 million ha of rice land in Asia. Farmers in flood-prone areas highly value rice that can withstand submergence for prolonged periods, such as Swarna-Sub1 (Arora, Bansal, and Ward 2019). Dar et al. (2013) also confirmed higher yields when submergence-tolerant rice variety Swarna-Sub1 was grown on fields submerged for as long as 7–14 days. Farmers indicated that salt-tolerant rice varieties were required, as salt-water intrusion had become a problem during the last several years. Clearly, the rising sea levels and problems linked with reduced availability of freshwater will lead to even higher demand for varieties that can cope with such environmental stresses without jeopardizing rice yields.

The International Rice Research Institute (IRRI), through the Consortium for Unfavorable Rice Environments (CURE), has continued to work with Myanmar's Department of Agricultural Research (DAR) to develop suitable rice varieties for challenging areas. This cooperation brings the prospect of additional promising varieties in the future. According to a former Deputy Director General of Department of Agricultural Research (personal communication, July 2017), a number of stress-tolerant rice varieties have been developed in Myanmar. Some of these varieties include Yemyokekhan 1 (Swarna-Sub1), Yemyokekhan 2 (BR11-Sub 1) for submergence tolerance, and Sangankhan Sinthwelatt (Salttol Sin Thwe Latt), Pyi Myanmar Sein (IR10T107), Shwe Asean (CSR 36) for salinity tolerance. Farmers can receive information on or seeds of these improved varieties from regional agricultural offices and seed farms. However, only a limited number of varieties are commonly grown by farmers in the Ayeyarwady delta. Farmers are only interested in those rice varieties that have a good market. As it takes at least 4–5 years to develop a new market, farmers tend to stick to their old local varieties. Farmers preferred varieties with quality characteristics of milled rice, such as fewer broken grains and high milling recovery. Both traits are mutually related and depend on variety type, environmental factors, and postharvest handling, especially moisture content of rice grains at harvest (Fan, Siebenmorgen, and Yang 2000).

Conclusions

This study provided evidence of on-farm rice varietal diversity in the Ayeyarwady delta, Myanmar and investigated the determinants of varietal selection on-farm. The assessment of the diversity status is the initial but essential step for the implementation of germplasm conservation strategies. These assessments are required both at the national level and in regional contexts. The rice variety diversity in the study area appeared to be quite high, and particularly rich in local landraces. Farmers grew predominantly traditional varieties over modern HYVs. The main drivers of varietal diversification were farmers' farming experience and education, which both positively increased the likeliness of growing more varieties at the same time. Furthermore, more varieties were grown by farmers in conditions less suitable for rice cultivation (saline water regions, undulated type of terrain, low-fertility soils), as a likely strategy to secure at least part of rice production under harsh conditions. These findings may be useful to form the basis for the formulation of farmer-oriented extension and research programs by helping to focus on a particular group of farmers. Unlike other studies, we observed reduced likeliness of HYVs adoption with higher education, which could be linked to the farmers' awareness of considerable input (labor and costs) requirements for HYVs cultivation and high risk of failure in case of limited access to irrigation, fertilizers, and pesticides. Except high yields, farmers wanted varieties that were resistant to environmental constraints; in our study especially resistance to saline environment, flooding, and pest infestation. From a policy perspective for high adoption of HYVs, incorporation of farmers' preferences in new rice varieties during the breeding process (such as resistant to environmental stresses or/and preferred qualitative rice properties) would increase the likelihood of adoption of those varieties. Though breeding cannot incorporate all desired attributes, the vital features, such as tolerance to biotic and abiotic stresses, should be introgressed in particular varieties, so that they can meet the demands of farmers. As market also plays an important role in farmers' preference for cultivars, there is a need to develop the infrastructure to support the formation of niche markets.

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