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Diversity of Rice Varieties and Cropping Systems in Bangladesh Deepwater Areas

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Abstract

Sixty-eight indigenous rice cultivars collected in deepwater areas in Bangladesh were examined in terms of heading behavior and allozyme variation. Seasonal ecotypes differed in the heading behavior for adaptation to their respective cropping seasons. Isozyme analysis revealed that cultivars grown in deepwater areas in Bangladesh consisted of a Japonica-like group and unclassified unique group in addition to a major Indeca group. Classification by isozyme variation was not necessarily consistent with the differentiation into seasonal ecotypes. Cultivars collected in a restricted area in Khulna District consisting of various seasonal ecotypes showed a genetic similarity to each other, suggesting that geographical differentiation preceded seasonal differentiation. Based on a case study conducted in 2 villages in Khulna, it was pointed out that diverse landraces which are adapted to different local and seasonal conditions have evolved by interacting with traditional planting systems.

Discipline: Genetic resources
Additional key words: heading behavior, isozyme, varietal differentiation

Introduction

Bangladesh is situated in the wide delta of the Ganges, Brahmaputra and Meghna rivers. Average annual rainfall is about 2,000 mm, with 95% being concentrated from May to September. In addition to rainfall, melting of snow in the Himalayas leads to the rise of the river water level during the monsoon period and more than half of the total land of the country is flooded. In the flood-prone low-lying areas, rice is the major or sometimes the only crop that can be cultivated.

Three cropping seasons of rice have been identified in Bengal (Bangladesh and West Bengal State of India), namely, Boro (winter), Aus (summer) and Aman (autumn)[10,12]. Varietal groups which are used for different seasons, are designated by the name of the respective cropping seasons. In the dry winter season, Boro is grown mainly in the irrigated fields. In the rainy summer season, short-duration Aus is grown in lowland as well as in upland areas. From summer to autumn, long-duration Aman is grown by transplanting (T. Aman) or by broadcasting (B. Aman). B. Aman rice is almost synonymous with deepwater rice that can elongate the internodes markedly in response to the rising water level. Furthermore, 2 minor groups of deepwater rice, Rayada and Ashina, occur in Bangladesh. Rayada shows a very long growth duration, and is cultivated in a restricted area along the river Madhumaty, a tributary of the Ganges. Ashina belongs to a small varietal group characterized by early heading.

Nearly 10,000 landraces are considered to exist in Bangladesh. These varieties have been generally considered to belong to the Indica type in the same way as those grown in other low-lying areas in tropical Asia. Isozyme studies, however, revealed that Bangladesh deepwater rice contains some varieties that did not fall under either the Indica or Japonica type[5,13]. The objective of the present study was to analyze the pattern of genetic variation among rice cultivars distributed in flood-prone areas in Bangladesh with special reference to varietal differentiation corresponding to the cropping seasons. A case study in Rayada-growing villages was conducted to analyze the diversity of rice cultivars in relation to the traditional cropping systems.

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Materials and methods

The present study was mainly based on the samples and information obtained during a study-trip to deepwater areas in Bangladesh in which the second author participated. The trip was organized in December 1989 through the financial support of a grant from Monbusho International Scientific Research (No. 0104110) and with the cooperation of the Bangladesh Rice Research Institute (BRRI). The details of the field observations were described in the trip report[15]. Sixty-eight rice cultivars dealt with in the present paper consisted mostly of landraces collected from farmers' fields or their seed stocks in the Districts of Dhaka, Habiganj, Sylhet, Mymenshingh, Tangail and Khulna. Twenty landraces provided by BRRI were also analyzed.

Collected seed samples were sown in mid-April in 1990 and grown in the automatic short-day (12.5 h) apparatus at the National Institute of Genetics, Mishima. The same set of samples was planted in paddy fields under natural daylength (not all the accessions were examined because of the shortage of plants). Heading date of each variety was recorded under short- and long- (natural) day conditions. Isozyme assay was conducted using plumules or germinated seeds derived from multiplied seeds. Eight loci (*Est2, Est5, Est10, Est11, Est12, Mal1, Mal2* and *Amp5*) were assayed by polyacrylamide gel electrophoresis (PAGE) and 12 loci (*Acp1, Amp1, Amp2, Amp3, Cat1, Est2, Est9, Pgd1, Pgd2, Pgi1, Pgi2* and *Sdh1*) by starch gel system. In PAGE, 22 landraces from Asian countries other than Bangladesh were analyzed together as check varieties. The details of the methods of isozyme analysis were described in the reports of Ishikawa et al.[14] and Cai et al.[4]. In the 2 villages of Surigati and Katadula (Khulna District), we tried to collect not only seed samples but also information about each variety through interviews with local people.

Results

1) Genetic diversity of landraces

(1) Heading behavior

Under the short-day conditions, all the cultivars examined flowered, while under natural daylength, only 40% of them flowered. The basic vegetative phase (BVP) was estimated for convenience by subtracting 35 days from the number of days to heading from seeding (DTH) under short daylength. The photoperiod-sensitive phase (PSP) was estimated by the difference between DTH under short and long (natural) daylength.

Table 1 shows the frequency distribution of BVP and PSP of the cultivars examined. Boro as well as Aus cultivars showed a short BVP and short PSP as expected. T. Aman seemed to contain the long and medium groups in BVP as well as in PSP. Among T. Aman cultivars, long BVP was associated with long PSP and medium BVP with medium PSP. The latter group may be the late planting T. Aman that is sown in August and transplanted in September. B. Aman cultivars showed a wide range of BVP and long PSP. Rayada showed a medium BVP and long PSP. Ashina showed a short BVP and medium PSP. The above characteristics of the respective seasonal ecotypes accounted well for their heading behavior in corresponding cropping seasons in Bangladesh. Rayada

Table 1. Heading behavior of rice cultivars collected in Bangladesh deepwater areas

Seasonal ecotype	Basic vegetative phase (days)								No. of cultivars
	60	70	80	90	100	110	120	130<	
Boro	5	2	1						8
Aus	6	1		2					9
T. Aman		1	3	3		1	3	3	14
B. Aman	2	11	5	8	3	1	3	1	34
Rayada			3		1				4
Ashina	1	3							4
Seasonal ecotype	Photoperiod-sensitive phase (days)								No. of cultivars
	0	20	40	60	80	100<			
Boro	2	4	1	1					8
Aus	2	3	1			1			7
T. Aman				4		6			10
B. Aman						28			28
Rayada					3	1			4
Ashina			1		3				4

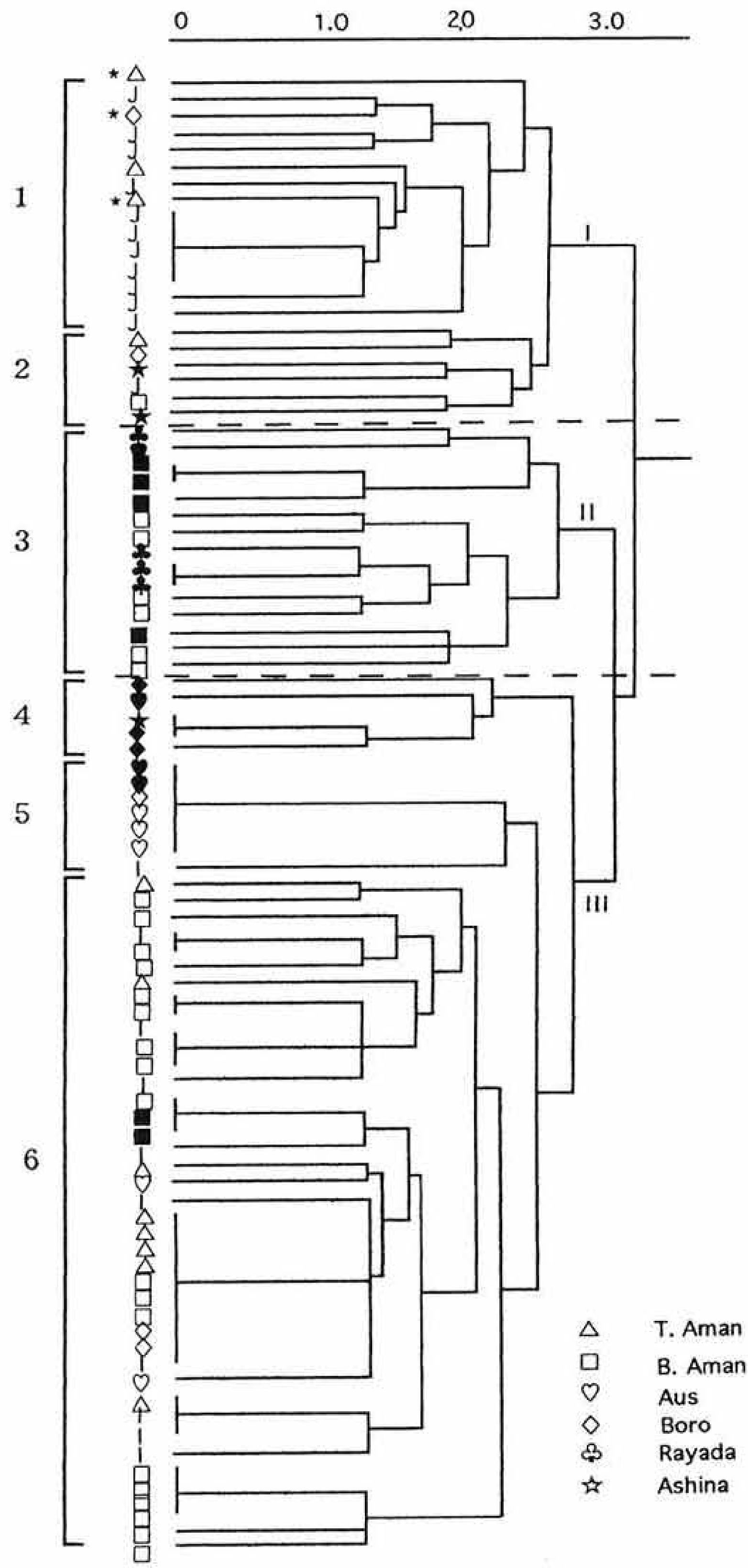

Fig. 1. Dendrogram of rice cultivars collected in Bangladesh deepwater areas constructed based on allozyme variation (see text)

Solid symbols stand for Khulna collection.

*Indicates small-grain scented rice.

I and J indicate Indica and Japonica check varieties, respectively.

Table 2. Classification of rice cultivars grown in Bangladesh deepwater areas based on allozyme variation and seasonal ecotypes

Isozyme[1)] cluster	a) Isozyme $\bar{D}$ score[2)]						b) Seasonal ecotype[3)]					
	0.2	0.3	0.4	0.5	0.6	0.7	BO	AU	TA	BA	RY	AS
1					1	2	1		3			
2					5		1		1	1		2
3		4	5	3	1	2				11	4	
4			5				3	1				1
5		1	5				1	5				
6	9	15	7	1			1	2	8	22		

1): Grouping based on 8 isozyme data.

2): Probability of belonging to Japonica type based on 12 isozyme data.

3): BO, Boro; AU, Aus; TA, T.Aman; BA, B.Aman; RY, Rayada; AS, Ashina.

has an extremely long growth duration in Bangladesh. It is sown from December to January, remains at the vegetative stage under short-day condition in winter, and flowers from November to December. In Japan, Rayada flowered in the summer at 120–140 days after seeding when grown under short-day conditions, suggesting that its insensitivity to short daylength in winter may be due to prolonged BVP caused by low temperature.

(2) Allozyme diversity

A total of 68 Bangladesh landraces, together with 22 Asian check varieties, were assayed for 8 isozyme loci by PAGE. Data were subjected to cluster analysis (UPGMA) and factor analysis. The 2 methods yielded largely similar results. Fig. 1 shows a dendrogram obtained from UPGMA. At the level of taxonomic distance 3.0, 3 groups, I, II and III, were recognized. Group I could be further divided into clusters 1 and 2. Cluster 1 included Japonica checks and a few particular Bangladesh varieties which consisted mostly of small-grain scented rice. Cluster 2 consisted of various seasonal types including 2 Ashinas. Bangladesh cultivars belonging to this group I can be considered to be close to the Japonica type, though they differed from typical Japonicas in carrying a few Indica-specific alleles such as *Cat1-1* (clusters 1 and 2) and *Mal1-2* (cluster 2). Cluster 3 (group II) consisted of B. Aman, Rayada and Aus varieties. They were characterized by the presence of specific alleles such as *Est10-4, Amp5-4* and *Est5-2* that all seldom occur in ordinary cultivars. *Est10-4* was specifically found in wild rice[19]. Group III could be divided into 3 clusters. Cluster 4 consisted of three Boros, one Ashina and one Aus. Cluster 5 consisted mostly of Aus varieties. The largest cluster 6 consisted of B. Aman, T. Aman and a few Aus varieties. Group III can be considered to belong to the Indica type, because Indica checks were widely distributed in this group.

To further examine the relations between the cluster structure thus obtained and Indica/Japonica differentiation, another data set of 12 isozyme loci obtained by the starch gel system was subjected to computation of Indica/Japonica discriminant score $\bar{D}$. This score represents the probability with which a strain with a given allelic composition belongs to typical Japonica type[17]. Table 2a shows the frequency distribution of $\bar{D}$ scores of Bangladesh cultivars classified into 6 clusters obtained by UPGMA. It was confirmed that clusters 1 and 2 (group I) can be considered to belong to the Japonica-like group and clusters 4, 5 and 6 (group III) to the Indica or Indica-like group. Cluster 3 (group II) showed a range of $\bar{D}$ scores. Since computation of $\bar{D}$ scores is based on the estimated frequency of the alleles commonly found in typical Indica and Japonica cultivars, the strains carrying rare alleles such as those in group II can not be correctly quantified by this measure.

Relationships between seasonal ecotypes and isozymic clusters are given in Table 2b. Boro varieties were found to belong to a diverse group at least in terms of allozyme variation. Aus varieties were classified into group III (Indica or Indica-like). T. Aman varieties belonged to mostly cluster 6 (Indica), though some were included in group I (Japonica-like). About two-thirds of the B. Aman varieties belonged to cluster 6 (Indica), but the remaining cultivars formed a unique group II (cluster 3) together with Rayada. Ashina belonged to either cluster 2 or 4.

2) A case study in Rayada-growing villages in Khulna District

In Khulna District (southwestern part of Bangladesh), rice fields are mostly rainfed, and 90% is flooded in the monsoon season (water depth is less than 1 m in 85% of the area and deeper than 1 m in 4%)[12]. We vis-

Table 3. Planting patterns under different water conditions and varieties used in the 2 villages in Khulna

Maximum water level	Planting pattern		
	Winter	Summer	Autumn
3 ft (92 cm)	Boro[a] (transplanted)	Aus[b] or Ashina[c] (broadcasted)	
3.5 ft (107 cm)	Boro[d] + Rayada[e] (transplanted)		
4.5 ft (137 cm)		Aus[f] + Aman[g]; Ashina[h] (broadcasted)	
8 ft (244 cm)		Aman[i] (broadcasted)	

Variety a): Kaliboro (transplanted in Dec–Jan, harvested in May–Apr).
b): Shuriborum.
c): Digha (harvested in Sep–Oct).
d): Sonarigia (transplanted in Jan–Feb, harvested in Apr–May).
e): Dhaki (harvested in Oct), Deshal (harvested in Nov–Dec).
f): Shadova (max water: 1.5 m), Ratul (max water: 1 m, harvested in July–Aug), Ratal.
g): Kalamoni, Bilpara, Khesail, Urmuni, Shadajabura, Defa, Palabili.
h): Kurmoni (max water: 1.5–1.7 m, harvested in early Sep).
i): Urichallha (max water: 2.4–2.7 m, sown in Mar–Apr, harvested in Nov–Dec).

ited 2 villages, Surigati and Katadula, which are about 20 km apart. Location- and season-specific planting methods have been applied to fit varying water regimes. The following information on cropping systems was provided by local people.

Four major planting patterns depending on the water conditions (mainly maximum water depth) are presented in Table 3. 1) At a relatively lower depth (maximum water depth of 3 ft), high-yielding Boro is cultivated by the transplanting method in the dry winter season, and then Aus (or Ashina) is broadcasted in the rainy season. 2) The fields where the maximum water depth is 3.5 ft are planted with a mixture of Boro and Rayada. Mixed Boro and Rayada (1 : 4) are sown in a nursery from December to January, transplanted from January to February, and Boro is harvested from April to May together with vegetative Rayada at the ground level under dry conditions. Ratooned Rayada plants regrow in response to rising water level, and mature in December. 3) In the fields where the maximum water depth is 4.5 ft, a mixture of Aus and Aman rice is broadcasted from March to May. Aus is harvested above the water surface together with the leaves of Aman from July to August. Aman continues to grow and is harvested from November to December. 4) At the deepest sites (maximum water depth of 8 ft), single B. Aman varieties are broadcasted.

Weedy rice called Jhora-dan is a noxious weed in Bangladesh deepwater rice fields. It was most probably derived from natural hybridization between cultivated rice and wild rice (*Oryza rufipogon* Griff.). If rice fields become severely infested with Jhora-dan, farmers prefer to plant Ashina instead of ordinary B. Aman. Since Ashina varieties flower from September to October 2 to 3 weeks earlier than Jhora-dan, it is easy for them to weed out Jhora-dan after harvesting Ashina crop. The seeds of Jhora-dan are sometimes harvested to supply food for the preharvest months of the main crop. Their shattered seeds are gathered from the ground.

We collected the seeds of 11 and 10 cultivars in Surigati and Katadula, respectively (Table 3). Interestingly, this Khulna collection, that consists of different seasonal types including non-deepwater rice, tended to cluster in Fig. 1 (solid symbols), indicating their genetic similarity. Farmers were using each variety depending on their differential adaptability to cropping seasons and to planting methods (single/mixed planting). For instance, they recognize that in the B. Aman varieties used for mixed planting, internode elongation is suppressed until the harvest of the Aus crop and then branching tillers elongate from the upper nodes, compared with B. Aman varieties for single planting.

Intra-population diversity in allozyme variation was examined in 5 cultivar samples and one Jhora-dan population. As shown in Table 4, they were polymorphic

Table 4. Intra-population genetic diversity assessed by 12 isozyme loci

Variety name (Ecotype)	No. of plants	Polymorphism parameters[a]		
		P	A	H
Kaliboro (Boro)	10	0.08	1.08	0.027
Ratal (Aus)	27	0.17	1.17	0.022
Defa (B. Aman)	27	0.58	1.67	0.062
Dhaki (Rayada)	15	0.42	1.42	0.134
Kurumoni (Ashina)	28	0	1	0
Jhora-dan (weedy)	20	0.92	1.91	0.322
Control [b]				
Landrace (10)		0.32	1.33	0.079
Weedy rice (7)		0.64	1.74	0.276
Perennial wild rice (10)		0.58	1.82	0.235
Annual wild rice (13)		0.21	1.21	0.056

a): P, Proportion of polymorphic loci.
A, Average number of alleles per locus.
H, Average gene diversity.
b): Mean of Indian and Thailand populations (6 isozyme loci, number of populations are in the parentheses).

except for an Ashina population (Kurumoni). Jhora-dan showed the highest diversity. The degree of intra-population diversity obtained in this collection was comparable to that observed in other countries (Table 4). In the Khulna collection, 3 varieties were common to the 2 villages and others were different judging from their vernacular names. Isozyme assay revealed that samples with the same name had not exactly the same isozyme genotype. This was not unexpected from their high intra-population polymorphism.

Discussion

Indigenous rice cultivars collected in Bangladesh deepwater areas showed a high degree of diversity in heading behavior as well as in allozyme variation. Different seasonal types were found to differ in their heading behavior, reflecting their adaptive differentiation to respective cropping seasons. On the other hand, varietal groups revealed by isozyme analysis did not exactly correspond to differentiation into seasonal types. As mentioned previously, the Khulna collection tended to show similar allozyme genotypes with each other, suggesting that geographical differentiation may have preceded differentiation into seasonal ecotypes.

It is generally considered that in tropical Asia, Indica-Japonica intermediate or unclassified atypical cultivars are distributed only in hilly areas[17]. All the Bangladesh cultivars dealt with in the present study showed Indica characteristics judging from the commonly used Indica/Japonica diagnostic traits such as phenol reaction, KClO3 resistance and apiculus hair length[15]. Our isozyme analysis, however, indicated that a few Japonica-like varieties (group I) and a unique group which could not be classified into either Indica or Japonica type (group II) occurred in addition to a major group classified into Indica (group III). It is likely that, group II in the present study that included Rayadas corresponded to "group IV defined by Glaszmann"[5]. Phenotypically Rayada varieties can be distinguished from ordinary B. Aman by their very long growth duration, tolerance to low temperature, insensitivity to short daylength in winter and absence of seed dormancy[6,8,16]. The present study demonstrated that the Rayada varieties were closely related to a part of B. Aman, in particular to the B. Aman, varieties collected in Khulna where Rayada was collected. Previously, Hakoda et al.[7] reported that deepwater rice distributed in the Bengal delta involved a varietal group close to Japonica type in allozyme variation in contrast to the deepwater rice varieties in the delta of Chao Praya and Mekong which all belong to the Indica type. Origin of Japonica-like and unclassified cultivars distributed in Bangladesh deepwater areas remains unsolved. The fact that the members of Group II harbored a particular allele specific to wild rice suggested that they are closely related to the wild progenitor. Thus genetic diversity in Bangladesh rice cultivars is important not only for rice breeding in future but also for evolutionary study in rice.

In Khulna, mixed planting of Boro and Rayada has been practiced in the areas where the water depth increases so rapidly in the rainy season that single Aus or Aman seeding is impossible after the Boro crop. Mixed broadcasing of Aus and Aman widely prevails in the Bengal floodplain[1]. According to Ando[2], transplanting of Aman after harvesting of Boro or Aus crop is too dependent on rainfall and therefore quite risky. Labor necessary for transplanting is another factor for farmers to prefer broadcasting. Thus, mixed broadcasting in Bangladesh may be considered to be a strategy for the efficient utilization of space by combining 2 varieties with different growth durations in areas where double cropping or single planting is risky or impossible.

The diversity of planting patterns promoted varietal differentiation, while the diversity of varieties enabled the farmers to adopt various planting patterns. Thus, cropping systems and rice varieties have interacted with each other and coevolved. Traditional cropping systems reflect farmers' indigenous knowledge to achieve a better yield by accepting the natural environment as it is. Recent development of agricultural techniques, however, aims at changing environments by controlling river water in the rainy season and supplying irrigation water in the dry season. A few high-yielding modern varieties grown under favorable conditions are rapidly replacing landraces in Bangladesh as in other countries[11]. Decreasing trend of landraces is particularly conspicuous in the Boro crop: the proportion of the area planted to local varieties was less than 20% of the total Boro area in the early 1990s[3]. To cope with genetic erosion rapidly proceeding in farmers' fields, collection and preservation effort have been extensively promoted at national and international level[9,18]. Presumably, the agricultural situation in Rayada-growing villages has substantially changed since we visited the area in 1989. Description of the Khulna villages presented in this paper reflects the diversity of rice cultivars maintained by traditional cropping systems that tend to be abandoned.

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