DEEP-WATER RICE IN BANGLADESH

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Introduction

Deep-water rice, floating rice and broadcast Aman rice are all synonymous. This crop is grown widely in Bangladesh and covers approximately an area of 2 million hectares. The production per hectare varies from 1.2 to 1.8 t. Almost 33 percent of the total population of Bangladesh depends on it as the major rice crop. Therefore, from time immemorial this crop is paying a vital role in the socioeconomic conditions of the people.

Floods occur in Bangladesh for two major reasons, high monsoon rain from May to September (about 160–170 cm) and large volume of water carried down from the Himalayan mountains by the rivers - the Ganges, the Jamuna, the Brahmaputra and their tributaries. About two-third of Bangladesh thus is flooded from 1 to more than 5 m in depth. The flooded period usually remains limited to June to October. Occasional flush flood may even occur in April and May causing serious damage to crops and the community. The areas where the flooding occurs are usually the river basins and the low-lying areas with R. L. values ranging from sea level to a maximum of 18 m. Under normal conditions, the flooding is gradual showing a mean increase of about 10 to 12 cm per day with a peak in August. It then gradually recedes and is no longer present by the end of October.

In areas adjacent to the main stream, flood normally brings down 40 to 50 kg of silt per square meter. The mean N, P_2O_5, K_2O and CaO deposited due to siltation are respectively 77.37, 19.40, 109.96 and 44.12 kg/ha. The silt thus deposits adequate quantities of N, K and Ca and the deep-water rice plants under normal flood conditions can use these nutrients to produce 2.7 to 3.0 t/ha of paddy (5). Therefore, flooding in one sense restores soil fertility. However, due to heavy siltation, riverbeds constantly rise, flooding more areas each year and causing recurrent loss to property. Under such a condition, farmers of low-lying areas cannot but grow deep-water rice during the monsoon season.

Nature of deep-water rice

Physiology: Deep-water rice is a physiological race of *Oryza sativa* L., is sensitive to photoperiod and flowers usually in October - November when the day length is reduced to about 11 hours.

The vegetative parts such as leaf sheath and blade and the internodes exhibit the capacity of elongation when subjected to submersion. The stem may elongate as much as 30 cm per day when subjected to flooding. Under flooded conditions the number of nodes may increase to 30 in comparison to 14 to 15 under nonflooded conditions. Each of the upper nodes (6 - 7 to above) may produce 2 to 31 adventitious roots and one tiller under flooded conditions (4).

Due to constant force of current and wind the deep-water rice plant may be uprooted but can survive and produce a normal crop depending on the time and stage when the plant is uprooted (2).

In Bangladesh there are long-stemmed rice varieties insensitive to photoperiod which have a limited elongation capacity. Such rice varieties are not grouped under the deep-water rice of Bangladesh.

The deep-water rice of Bangladesh which exhibits distinct sensitivity to photoperiod is classified into two groups.

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Group I : Deep-water rice or broadcast Aman

Within this group the following subgroups with distinct flowering time are :

Subgroup A : Bhadoia and Aswina. Usually less sensitive to photoperiod. Flowers normally in late August to September, flood resistance low. Mostly suitable up to 2 m flooding.

Subgroup B : True broadcast Aman. Photoperiod sensitivity high, flood resistance medium to high, suitable for 2.5 to 3.5 m of flooding.

Group II : Rayada

Photoperiod sensitivity very high, flood resistance as high as true broadcast Aman but without any seed dormancy and moderate cold tolerance at seedling stage. Therefore, can be seeded in November - December when the minimum temperature ranges from 8° to 10°C under field conditions of Bangladesh. Unlike other varieties of deep-water rice when seeded in November - December the plants will not flower in April/May due to short day induction but will continue to grow until next October when they will flower.

Broadcast Aman rice of Bangladesh may be considered as the derivative of *O. sativa* var. *fatua* Prain which is characterized by high seed dormancy, whereas the Rayada does not have seed dormancy. The Rayada of Bangladesh seems to be the most primitive group of rice varieties cultivated in Bangladesh.

Genetics: Deep-water rice varieties show distinct variability to the flooding depth. In Bangladesh there are varieties suitable for flood depth of 1 m, 1 to 2 m and 2 to 3 m. There are onlya few varieties that can tolerate a flooding depth of 4 m. Table 1 shows groups of local pure lines adapted to various flood levels.

Table 1. Classification of pure lines according to adaptability to different flood levels.

Pure line groups	Pure lines (No.)	Flood level
Bagdar, Fulkari, Bazail, Karkoti, Birain, Kali Mekri, Joal Bhanga, Bogu Aman, Pankiraj, Parsum, Jilbadam, Murail, Gutak, Lara Aman and Chaplash	106	Low
Laki and Badal	122	Low-medium
Bhadoia, Aswina and Bamoia	59	Medium
Khama, Dhala Amen, Lal Aman, Kala Aman, Matia Aman, Guai and *O. sativa* var. *fatua* Prain.	140	High

Breeding of deep-water rice

Breeding methods so far applied in Bangladesh are conventional systems of pure line selection and hybridization. Up to now appreciable success could not be achieved by the introduction of exotic varieties. Mutants have not been tried in the breeding of deep-water rice. In Bangladesh, breeders adopted the following objectives.

1. ability to withstand complete submersion for at least 72 hours between the age of 30 and 40 days,
2. at least 10 to 15 cm rate of continuous elongation of the plant from the age of 30 days for about 1 week.
3. increase number of nodes and internodes beyond 15,

4. leaf sheath and leaf blade elongation,
5. ability to produce abundant active nodal roots and tillers,
6. appreciable photoperiod sensitivity and cold tolerance at the reproductive stage.

At one time as many as 600 pure lines were used as a source of genes. Apart from these, there were Rayada and half a dozen variants of *O. sativa* var. *fatua*. The latter was used frequently to transfer the genes for longer leaf sheath and blade and higher number of nodes and internodes. There was occasional use of nonfloating rice to increase the magnitude of the yield components.

Very recently gene sources from exotic materials from different countries and modern varieties are used to incorporate genes for high yield. Attempts have been made to incorporate drought resistance and higher basal tillers in the newer deep-water rice varieties.

Selection Method of Segregating Population: In the past, F_2 materials were grown under normal field conditions. In some cases F_2 materials were divided into 3 bulks and were grown in shallow (up to 2 m), medium (up to 2.5 m) and deep (more than 2.5 m) flooded conditions. The success of selection depended on the flooding conditions. For instance, the F_3 and subsequent generations had to be bulked until the desired flood conditions occurred for effective selection.

Once there was an effective selection, the selected heads were grown in head rows for homozygosis. Usually, promising segregating materials were bulked for further testing under heavy flooded conditions. The homozygous lines were tested for elongation ability by growing selected plants in pots and submerging those in deep tanks. Suitable selected lines were then put in replicated yield trials for further selection of the variety.

This method was lengthy and uncertain because effective selection could not be made due to the lack of high flood every year. On the other hand, segregating generations could not be grown in the dry season to accelerate the selection work. However, BRRI has now facilities consisting of a battery of tanks which can be flooded to variable depths and dried out at will (Fig. 1). These facilities will then accelerate the selection work and rapid progress can be expected.

The breeding for resistance to *Ditylenchus angustus*, tungro, bacterial leaf blight, stem borers, leafhoppers, leaf folders, ear-cutting caterpillars are yet to be undertaken. A good number of sources of genes resistant for diseases except for *D. angustus* are available and sooner or later such diseases might get under control. Up to now only one Rayada strain (R16-06) has shown a high degree of resistance to *D. angustus*.

Results

By using simple pure line and hybridization techniques, the breeders have developed up to now 10 varieties suitable for various flood levels (Table 2).

Habiganj Aman I is moderately sensitive to photoperiod and flowers in early October. The rest of the varieties are highly sensitive to photoperiod and flower from late October to mid-

Table 2. Varieties suitable for different flood levels.

Name of varieties	Origin	Flood level (m)
Habiganj Aman I	Pure line	up to 1.5
Habiganj Aman II	Pure line	1.5 ~ 2.5
Habiganj Aman IV	Pure line	
Habiganj Aman VII	Hybrid	
Gabura	Pure line	2.5 ~ 3.0
Maliabhangar	Pure line	
Habiganj Aman III	Pure line	3.0 ~ 3.5
Habiganj Aman V	Pure line	
Habiganj Aman VI	Hybrid	
Habiganj Aman VIII	Pure line	

November. These are also fairly tolerant to cold (18°-20°C) at the reproductive stage. The yield potential under average field conditions varies from 2,300 to 2,800 kg/ha (3).

Most of the deep-water rice varieties of Bangladesh are fairly resistant to drought at the seedling stage. Therefore, all of the deep-water rice varieties so far developed exhibit resistance to drought at the seedling stage.

The resistance to flood in the existing deep-water rice varieties is due to the following factors.

1. ability to increase the length of leaf sheath and blade,
2. production of 8 to 10 extra nodes, internodes and leaves, and
3. internode elongation

Problems to be solved

The varieties developed so far perform well in the eastern zones where the soil pH varies from 4.5 to 5.5. These are poorly adapted to Gangetic floodplain where the soil is calcareous and pH varies from 7 to 8. Therefore, varieties are to be developed for these areas which represent about 46.9 percent of the total deep-water rice land.

The total produce of a rice crop is the sum of grain and straw. In the traditional, high-yield potential and deep-water rice the total produce depends upon the grain-straw ratio (Table 3).

Table 3. The total produce of various rice crops.

Crop	Grain-straw ratio	Grain yield (t/ha)		
		Grain	Straw	Total
Modern	1 : 1	5.0	5.0	10.0
Traditional-upland and transplant crops	1 : 2	2.5	5.0	7.5
Deep-water rice	1 : 5	2.0	10.0	12.0

The total produce of traditional upland transplanted varieties is the lowest whereas the deep-water rice yields the highest. The nutrients available to the deep-water rice plants from flood water, silt, and soil are mostly used for the vegetative parts. The major problem associated with the existing plant type is to increase grain production without reducing the length of the deep-water rice plant.

The major insect pests of deep-water rice are stem borers (T. *incertulas, C. polychrysa*), hispa (*D. armigera*), ear-cutting caterpillar (*M. separata*), rice bug (*L. acuta*), and leaf folder (*C. madinalis*) (1). Among the diseases, bacterial leaf blight (*X. oryzae*), blast (*P. oryzae*), tungro and ufra caused by *Ditylenchus angustus* (Bt1) Filipjev are very important and occasionally cause significant damage (6). Fish, rats, crabs, snails, etc., also cause sporadic damage. Apart from these, there are localized problems of stagnant and tidal floods, uprooting of the rice plant due to strong current and entrance of waterhyacinth which also cause appreciable damage to deep-water rice crops.

Prospect and new technology

Despite the cost involved and the time and effort required, a programme aiming at taming the flood by embankment, dredging of riverbeds, excavation of new canals, has been initiated in selected parts of the country.

Breeding techniques have not yet markedly changed. However, additional physical facilities to test the breeding materials for submergence and flood tolerance are being developed. Tanks to produce artificial flood-at-will are now available. Each of these tanks can be independently flooded or drained to subject breeding materials to variable flood depths for

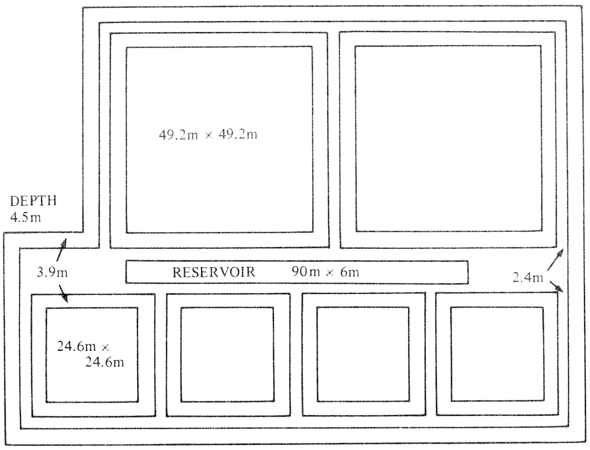

Fig. 1. Plan of tanks for testing deep-water rice plants.

different durations (Fig. 1). Tested and selected lines can be transferred and transplanted in normal irrigated fields for the production of seeds. Therefore, the tanks can be repeatedly used to test a large number of breeding materials in any season to accelerate breeding work.

Modern rice varieties are now used as a source of genes for high yield. Initial work reveals that a large scope is open for studies aiming at incorporating these high yield genes in the deep-water rice plants. The genes for rapid elongation of vegetative parts such as sheath, blade and internodes when combined with extra number of nodes and internodes, higher grain yield and resistance to specific diseases and pests will certainly produce the desirable variety.

On the other hand, the concept of flood resistance as revealed by the water lilly plant indicates that the ability of stem elongation is not the most essential trait for flood resistance. The rapid elongation of leaf petiole to keep the lamina above the water surface seems to be one of the most desirable traits. Therefore, in the future deep-water rice plant, the new architectural model will contain the following features.

Leaf

1. During the flood rapid elongation of 6th to 10th leaves (including sheath) with low senescence.
2. Glabrous, thick, and medium sized leaves with high chlorophyll content.
   The idea is to develop a plant which during the flood period will produce as many leaves as needed so that the leaf blades will always remain above the water surface to provide higher rate of carbohydrate production for the proper growth of the submerged organs. A glabrous leaf will assist the plant to remain afloat and erect because silt and clay particles will not adhere to a smooth leaf surface.

Stem

There may be several choices.

1. Ability of rapid elongation of internodes from the 4th upwards.
2. Larger number of nodes and internodes up to a total of 25 to 30.
3. Normal growth of nodes and internodes as in nonflooded conditions but with greater leaf elongation capacity under flooded conditions.
4. Nodes and internodes may not elongate (as in true hydrophytes like water lilly).

Such a plant will also require greater elongation capacity of leaves under flooded conditions. It must be noted that 3 and 4 plant types do not exist but there are positive evidences that such plant types can be reproduced.

Tiller

1. Higher number of basal tillers, and
2. Production of at least one tiller from 10th node upwards when the flood water starts receding.

Internal stem structure

Internodes normal like the existing types: That is, a larger diameter with a bigger lumen with normal vascular system and accompanying air spaces in the ground tissue. A larger diameter may provide more buoyancy but will facilitate the growth of the larvae of the stem borer.

Normal diameter with narrow lumen: Most of the space will be occupied by tissue system with well differentiated vascular bundles and adequate number of larger air spaces. Therefore, the total volume of the air space will be equal to that of the above. A narrower lumen with more air spaces in the ground tissue may give adequate buoyancy but the narrower lumen will inhibit the growth of the stem borer larvae.

Root

1. More basal roots for stronger anchorage.
2. More adventitious roots from all of the nodes during flood and post-flooded conditions to derive maximum nutrients from suspended silt and from soil.

Greater cooperation

1. Countries having active vigorous programme of breeding of deep-water rice may cooperate to complement work in testing and raising advance generations which cannot be obtained by some countries due to ecological barrier.
2. Exchange of breeding materials.
3. Monitoring tour in the breeding stations to observe the performance of breeding materials under different agroecological conditions.
4. Exchange of information, meetings in seminars and workshops.

All of these need extra finance and facilities. International organizations can play a vital role to assist and coordinate such affairs.

Summary

Deep-water rice, floating rice and broadcast Aman rice are all synonymous. There are about 2 million hectares covered by this crop. Almost 33 percent of the total population of Bangladesh depends on it. The flood is caused by torrential monsoon rains and large volume of water carried down by big rivers. Floods start in May and recede in October. The depth of flood may vary from 1 to more than 5 m. The flood carries 40 to 50 kg of silt per square meter. Approximately 77.37, 19.40, 109.96 and 44.12 kg/ha of N, P_2O_5, K_2O and CaO, respectively, are deposited due to siltation. This thus enriches the deep water soils.

Deep-water rice is a physiological race of *O. sativa* L and is characterized by the ability of elongation of vegetative parts under flooded conditions. It is sensitive to photoperiod and may become perennial by forming woody root stock. Rayada is another group of deep-water rice which differs from true deep-water rice by the absence of seed dormancy and by the presence of higher sensitivity to the photoperiod. The flood resistance is a genetical character and deep-water rice varieties can be grouped accordingly.

Up to now breeding work has been based on either pure line selection or hybridization methods. There are 10 improved varieties suitable for different flood levels. In order to increase the per acre yield of deep-water rice varieties, gene sources from modern varieties

are being used. For rapid selection, the hybrids are grown and tested in artificial water tanks where water depths can be controlled. Incorporation of resistance to major diseases and insect pests in the future deep-water rice varieties will be a major strategy in the breeding programme in addition to resistance to submergence and increased flood level.

An ideal plant type for deep-water rice will include ability of the plant to produce increased number of nodes and internodes and more leaves with rapid elongation capacity under flooded conditions. The ability to produce nodal roots and tillers will also be advantageous.

Cooperation at international level among breeders will accelerate the breeding work.

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Discussion

Y. Ohta, Japan: Your presentation of the future plant is very interesting. Your idea of having a great number of basal tillers with a large-diameter stem is suitable for rapid water movement However, in areas where the water is stagnant or where the flow is slow, another type of plant could be considered. Such plant would have no basal tillers, but a slender stem with longer internodes and fewer leaves until nodal tillers appear. In other words, the stem would be just sufficient to support the portion emerging above the water level. The plant should have nodal tillers which would develop at the time when water recedes. The nodal tillers should have vigorous stems with a large diameter. Such plant type could save energy at the time of growth.

Answer: I agree with you. When an early flush of tillers from the upper nodes appears after the water level gets lower, in early July, the cells of the inter-nodes located above and below the nodal tillers become differentiated and end their elongation. When in late July or in August another flush flood occurs, such tillers usually fail to elongate fast enough and many of them perish. Sometimes the plant becomes uprooted by strong current. Therefore, depending on the situation, the breeder must allow a certain amount of flexibility on tiller formation, particularly in the early stage of formation.

N. Murata, Japan: You mentioned that many problems must be solved in deep-water rice, including resistance to diseases and pests. Where is it possible to find germ plasms for such characters?

1. Are there such genes in floating rice because floating rice belongs to a large group including wild species?
2. Is it possible to introduce useful genes from cultivars which differ from floating rice without affecting the floating behaviour?

Answer: At present, when we are evaluating the local and exotic germ plasms we are finding that most of the desirable genes such as tolerance to drought at seedling stage, basal tillering, resistance to BLB, RTV, blast, "ufra" and tolerance to cold at the reproductive stage are available in the deep water variety. Certain high-yielding cultivars like BR4 (IR5 x IR20) and IR20 and BR3 have shown good combining ability with deep water rice and act as a source of high-yield genes to be incorporated in deep water rice.

G. S. Khush, The Philippines: Are you doing any research on cropping patterns for deep-water rice? In Burma, farmers skip the floating rice crop but transplant rice seedlings after the water recedes. As a result, they usually get higher yields. Are you practicing this cropping pattern in Bangladesh?

Answer: Yes, the Rice Cropping system and Applied Research Divisions of BRRI are working on this problem. We also did some work with mixed crop of deep water rice and Aman rice. The method of transplanting rice after the flood recedes is a common practice in shallow flooded areas from which flood recedes by mid-September. Farmers are now growing early varieties of deep water rice to make room for wheat, potato, legumes, etc. to be grown in November - December after the harvesting of deep water rice. Recent study on relay crop of deep water rice within the strips of Boro HYV crop is showing encouraging results. Such work will continue to increase the cropping index in flooded areas.

J. T. Rao, India: You mentioned the relationship between smaller lumen size in the culm and borer resistance. As we know, water plants survive well in view of the adaptation of the large lumen in the stem. Would selection for smaller lumen defeat the purpose for deep water rice? Have you screened the germ plasm for this character and do you know whether the character is genetically transferable?

Answer: In TKM 6, Habiguny Boro II and wild deep water rice, the lumen size is smaller and these are fairly resistant to yellow borer which is the predominant pest of deep water rice in Bangladesh. What I suggested was to keep the total volume of the air-space of the inter-node constant by increasing the size of the air spaces in the ground tissue system with corresponding decrease in lumen size. The lumen size of deep water rice stem increases during the critical stage of rapid internode elongation by disintegrating the central cells to get more energy for the plant when leaves are struggling to keep afloat as photosynthesis decreases. Therefore, there is no genetical problem to transfer such genes from one to another.