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Resilient Rice (Bao Dhan) for Rising Waters

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Abstract: Rice serves as the primary food source in many regions of North Eastern and Southern India. Consequently, the population of North East India, particularly in Assam, relies heavily on rice farming and its yield. However, the state of Assam faces significant challenges due to flooding during the monsoon season. Majority of rice varieties cannot withstand the stress caused by prolonged submergence. As a result, farmers are limited to cultivating deep water rice varieties during this period. Their exceptional tolerance to water stress has become a significant area of interest. The unique ability of elongation and kneeing of the stem helps the plant to survive through submergence and carry out all the necessary metabolism to keep the plant alive. Apart from its submergence tolerance property, it is also rich in essential minerals, vitamins, proteins, and antioxidants. However, its yield is lower compared to conventional rice varieties. Few breeding initiatives have produced some cultivars that are now recommended for agricultural use. But not much effort has been made to elevate the productivity of the landraces. Therefore, there is an increasing necessity for biofortification and enhancing the productivity of deep water rice in recent times. Conservationists have implemented various strategies to preserve the germplasm of deep water rice cultivars.

Keywords: Anthocyanin; Anaerobic germination; Conservation; Deep water rice (DWR); Elongation; Flood tolerance; Nutritional value

Introduction

Rice (*Oryza sativa* L.) contributing for more than half of the world's population is cultivated on 161 million hectares, producing on average 678.7 million tonnes annually (Vibhuti *et al*, 2015 a&b; Khatri *et al,* 2020). Abiotic stresses like drought and salinity are two major determinants due to their wide occurrence and high magnitude of impact (Vibhuti *et al,* 2015a; Bargali *et al,*2007). Rice is considered as sensitive to drought stresses (Lefevre *et al,*2001; Pandey *et al,* 2011), hence its productivity can be affected due to addition of water and low amount of water supply (Flowers and Yeo, 1995; Munns, 2002; Bargali *et al,* 2009). In recent years, salinity and invasive plants pose as major constraints to increased rice productivity globally in rice growing countries after drought (Gregorio, 1997; Negi *et al,* 2023; Joshi *et al*, 2024).

Assamsituated in the North-Eastern corner of India, has a pronounced individuality. It is intervening high Asia and Indo-China covering an area of 78,438 km^2 which is 2.39% of the total geographical area of India(Ahmed *et al,* 2011).The economy of the state is primarily an agrarian economy with 70.4 % of its population thriving in rural areas, and depends predominantly on agriculture and other allied activities. Agriculture serves as the backbone of Assam's economy. Agriculture in Assam is informally known as "rice culture", because with reference to area, production and productivity, it is mainly dominated by rice as the most important cereal crop. Rice cultivation has played a central role in improving food security in Assam and 90% of the state's population consumes rice (Pegu and Hazarika, 2016). According to the Economic Survey of Assam 2023-24, for the year 2022-2023 (P.E.) the rice production in the state is 6.04 million tonnes with an average yield of 2652 Kg ha^{-1}as compared to the production of 4.38 million tonnes with an average yield 1886 Kg ha^{-1}in the year 2021-22. Basically rice is categorized into four groups according to the season of harvest. They are Spring/Summer rice or Boro rice, Autumn rice or Ahu rice, Winter rice or Sali rice and Bao or Deep Water rice (Pegu and Hazarika, 2016) cultivated before the onset of monsoon season. The Economic survey of Assam 2023-24 reported that in the year 2022-23, rice production increased by 37.93% where the average yield of Boro rice increased by 29.99%, Ahu rice increased by 2.72% and Sali rice increased by 44.38% in comparison to the rice production of the year 2021-22. In addition to that, the area under summer rice increased by 1.89% however, area under Autumn rice decreased by 26.85% and under winter, rice decreased by 1.28% in 2022-23. Assam has a sub-tropical climate with warm humid summer days accompanied by cool dry winter days. The state receives an average annual rainfall of 2297.4mm as it is located in high rainfall zone. Assam receives 2% of total rainfall in winters *i.e.,* January and February, 25% in summers *i.e.,* March to May, 65% in the monsoon *i.e.,* June to September and 7% during post-monsoon period *i.e.,* October to December. Therefore, Assam is highly affected by floods during the monsoon season.

DWR is a type of rice that is capable of thriving in waterlogged environments. Approximately 100 million individuals across various regions of Southeast Asia rely on deep water rice varieties, particularly in areas where severe flooding significantly impacts agriculture during the monsoon season. This rice variety uniquely endures such challenging conditions without a decline in productivity and is regarded as a boon for the inhabitants of flood-prone regions in Assam (Rohilla *et al*, 2019). In addition to its ability to thrive in deep water, it offers numerous beneficial and nutritional properties. These deep water rice varieties are referred to as Bao dhan and about 20 to 30 varieties are cultivated in few pockets in Assam. The planting of all deep water rice varieties in Assam typically occurs between March and April, with a maturation period of around 300 days. Nevertheless, a significant disadvantage of cultivating is its relatively low yield (Rohilla *et al*, 2019).The primary objective of this research is to provide a comprehensive overview of deep water rice in Assam and to emphasize the investigations conducted to comprehend the plant's mechanisms for surviving submersion due to flooding.

Morphology

Under conditions of flooding, deep water rice can attain a height of upto 2 m. Rising floodwater levels during the early vegetative phase (4-6 weeks post-germination) trigger a significant increase in plant height. In the later vegetative stage, the rate of stem elongation progressively declines. Although daily elongation can peak at 25 cm, this is highly dependent on both water level and genotype. The red coloration observed in most varieties is likely attributed to differential anthocyanin accumulation within the starchy endosperm and aleurone layer(Rajkhowa and Borgohain, 2025).The mature seed features an elongated awn. The stem or culm does not grow fully erect; rather, it exhibits a zigzag configuration when submerged. Plants cultivated in deep water conditions demonstrate reduced tillering, with the primary tiller being taller than the secondary tillers, in contrast to those grown in normal water conditions, which exhibit rapid tillering. As the water level rises, branching ceases; however, a few branches may emerge from the nodes below the water surface once the water level stabilizes. Adventitious roots initially develop from the uppermost nodes situated just beneath the water's surface, enabling them to absorb nutrients and minerals from the aquatic environment. As these roots grow in submerged condition, the first node progressively produces several unbranched and thicker roots. Adventitious roots that develop from nodes submerged in water are believed to enhance nutrient absorption. As the floodwaters recede, the plant may collapse; the upper portion of the shoot remains oriented upwards due to kneeing, a form of negative gravitropism occurring at the higher nodes. As the water level continues to drop, certain adventitious roots extend into the soil, and kneeing ensures that the panicle remains above the water even during the ripening phase (Catling, 1992). Notably, deep water rice exhibits a greater leaf count, longer panicles, and an increased number of spikelets per panicle when compared to crops cultivated in non-deep water conditions, highlighting their affinity for water (Rohilla *et al*, 2019).

Genetics of the Plant

The genetic makeup of these varieties is what makes them so unique and able to withstand submergence stress during heavy and prolonged flooded conditions.

Various studies were carried out to understand the cause of their unique ability of flood tolerance. In the 1990s, researchers in rice genetics discovered that tolerance due to submergence in certain rice varieties is governed by a one significant quantitative trait locus (QTL), designated as SUB1 (Xu and Mackill, 1996). During 2002, the SUB1 QTL was successfully introduced into a widely cultivated rice variety of India known as Swarna through marker-assisted backcrossing (MAB). This hybridization method involves transferring a specific gene from one plant to another via traditional breeding techniques rather than genetic modification. Swarna was chosen for this process due to its popularity among farmers in the region, which would likely encourage the adoption ofthe Swarna-Sub1 variety (Yamano *et al,* 2013). Both deep water and non-deep water rice varieties possess

Figure 1: Panicles of different DWR

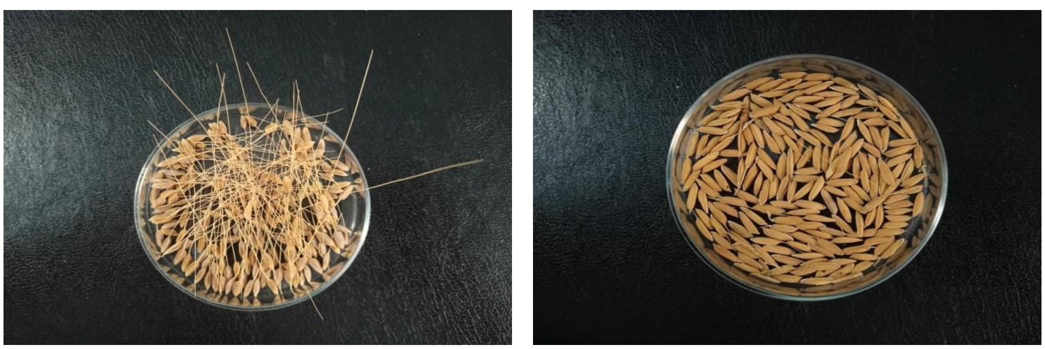

Figure 2 (a): Pani kekowa Bao (b) Borehha Bao

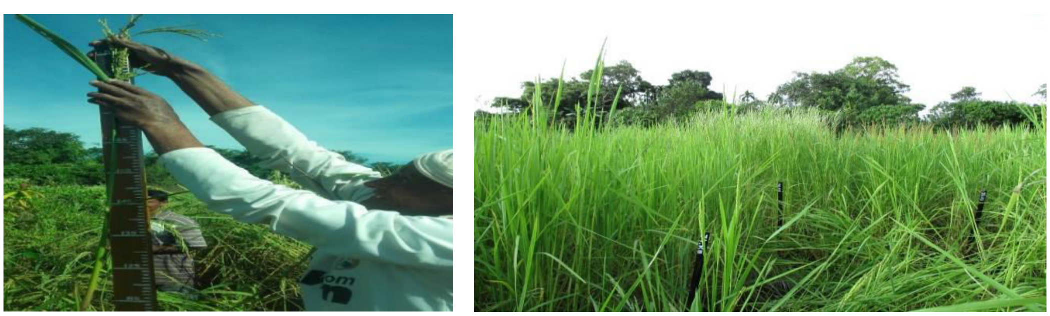

Figure 3: (a) A worker measuring the height of an individual plant (b) DWR in field condition

identical mechanisms for internode elongation. However, the latter are unable to initiate the necessary responses to endure flooding, whereas the former can do so with relative ease. This capability is attributed to the significant quantitative trait loci

(QTLs) they possess, which enable growth even under submerged conditions (Hattori *et al,* 2007). Genetic analysis has identified that these critical QTLs are situated on the long arm of chromosome 12 in the cultivars (Hattori *et al,* 2007).Moreover, deep water rice has a specific group of protein called Expansin which facilitates the long-term extension of isolated cell walls. Research indicates that alpha expansins exhibit reduced activity in the cell walls of grass families when compared to their performance in dicotyledons (McQueen-Mason *et al*, 1992; Cho and Kende, 1997). Additionally, monocots such as maize and rice possess a greater number of putative beta-expansin genes than Arabidopsis (Cho and Cosgrove, 2000). These proteins are categorized into two related families: alpha and beta-expansins (Lee and Kende, 2001). It has been determined that beta-expansin genes are responsible for the rapid elongation of internodes in deep water rice varieties, and their expression is stimulated by gibberellin and injury (Lee and Kende, 2001). The influence of ethylene on stem elongation is notably substantial. Under conditions of deep water, ethylene accumulates within the plants, and this increase in ethylene concentration triggers the expression of two specific genes, SNORKEL1 and SNORKEL2. The products of these two genes govern the response to submergence, leading to internode elongation facilitated by gibberellin, which assists plants in avoiding submergence. The absence of these two genes was observed in the non-deep water rice variety (Hattori *et al,* 2009).

Cultivation

Deep water rice is grown in several countries, including India, Bangladesh, Thailand, Myanmar, Vietnam, Indonesia, and Guinea (Tarafder *et al,* 2022). In India, the states that primarily cultivate deep water rice are Assam, Bihar, West Bengal, Odisha, Uttar Pradesh, and certain areas in South India. Within Assam, the Brahmaputra valley serves as the principal region for the cultivation of DWR (Rohilla *et al,* 2019). In Assam, various ethnic groups have been engaged in the cultivation practices of DWR for centuries, residing in the Brahmaputra river basin (Loying *et al,* 2010). The region employs diverse sowing techniques; in Bao areas, monoculture of Bao rice is practiced, while in Ahu areas, a mixture of Ahu and Bao seeds is sown in a ratio of 4:1 (Rohilla *et al,* 2019). Typically, seeds are directly sown into the soil at a rate of approximately 60-130 kg/ha prior to the arrival of the monsoon season (Rohilla *et al,* 2019). Cultivation practices must consider planting variables as significant factors. In a study on planting variables, it was found that, 20 cm × 15 cm spacing with five seedlings per hill demonstrated superior growth characteristics.

Conversely, a planting variable of 30 cm × 20 cm spacing with five seedlings per hill yielded better results in semi-deep water conditions within the New Alluvial Zone of West Bengal (Tarafder*et al,* 2022).

Nutritional Value

Bao Dhan, possesses a superior nutritional profile when compared to other enhanced rice varieties. Additionally, certain cultivars from Assam, including Negheri Bao and Jul Bao, exhibit significantly elevated protein levels relative to other rice types. Their richness in iron, zinc, vitamins, minerals, and anthocyanins contributes to their classification as highly nutritious (Rohilla *et al,* 2019). Anthocyanin, a polyphenolic pigment present in various flowers, fruits, vegetables, and leaves, contributes to the purplish hue of majority of deep water rice kernels (Rajkhowa and Borgohain, 2024). This pigment is recognized for its in vitro properties, which include anti-oxidant, anti-inflammatory, anti-cancer, and anti-microbial effects.Earlier research indicated that pigmented rice contains higher levels of total phenolic compounds (TPC) compared to non-pigmented rice (Chen *et al,* 2012). The significance of red kernelled deep water rice was highlighted when it was discovered to be a nutritionally beneficial variety, possessing antioxidant properties attributed to its elevated anthocyanin content (Loying *et al,* 2010). Given that anthocyanin is recognized as a highly effective antioxidant, red rice with substantial anthocyanin levels is also considered nutraceutically valuable (Kalita and Handique, 2021).

Rice serves as a significant source of dietary energy, primarily due to its starch content, which constitutes approximately 90% of milled rice on a dry weight basis. Starch is the predominant component of rice, contributing over 80% of its total composition. It plays a crucial role in determining grain quality, particularly in relation to cooking and eating characteristics (Patindole *et al,* 2015). Starch is composed of two main components: amylose and amylopectin. The ratio of these components influences whether the rice becomes sticky and gelatinous or remains non-sticky after cooking. Sticky rice is characterized by a higher amylopectin content and a minimal amount of amylose, while non-sticky rice contains more amylose than amylopectin, resulting in separate grains post-cooking. A comparative field study examining deep water tolerant and intolerant rice varieties revealed that seedlings of the tolerant ones possess 20-30% more starch content compared to intolerant counterparts. This stored starch is utilized during submergence for ATP production during germination, facilitating rapid growth to keep pace with rising water levels and avoid submersion (Kutschera and Hoss 1995; Sarkar *et al,*1996). In water-logged conditions during deep water floods, growth rates of the varieties have been observed to reach up to 25 cm per day (Vergara *et al,* 1976).

From a nutritional perspective, the most notable feature of deep water rice is its elevated protein levels. Typically, the protein content in rice ranges from 6% to 14%, with an average of 9.5% (Gomez, 1979) or 10.5% (Baruah *et al,* 2006). Research conducted on ten indigenous land races of deep water rice in Assam revealed crude protein levels between 8.03% and 13.20%, with an average of 11.78%. Deep water rice landraces, particularly Basmati genotypes, are generally noted for their high iron content (Ravindra, 2013). A research study carried out in Majuli, Assam, involving ten varieties of DWR, *viz.* Amona, Maguri, Rangoli, Kakua, Panikakua, Deoribao, Moimonsingia, Duatkalam, Dalbao, and PJNB-96-10observed that Duatkalam exhibited the highest iron concentration, as determined colorimetrically following Wong's method (1928).Red rice is abundant in fiber, vitamins B1 and B2, as well as iron and calcium. It is recommended for individuals with heart conditions and diabetes due to its superior nutritional profile and health benefits (Maibangsa *et al,* 2023). Additionally, red kernelled deep water rice, which is high in zinc, promotes faster wound healing and enhances the body's immune system to operate efficiently (Chowdhury *et al,* 2016). Zinc serves as an antioxidant, aiding the body in defending against the detrimental effects of free radicals, which can potentially harm tissues and cells. A single serving of red or brown rice can supply 23% of the daily requirement of vitamin B6 necessary for the optimal functioning of bodily organs. Additionally, lowering LDL (low-density lipoprotein) cholesterol levels can diminish the risk of heart-related issues and help regulate blood sugar levels (Maibangsa*et al,* 2023).

Anaerobic Germination

Hypoxia or anoxia primarily affects plants as a result of flooding or waterlogging, as well as during the development of various plant organs, including seeds. Numerous plant species are susceptible to flooding. However, certain plants, such as rice, exhibit a degree of tolerance to such conditions. Notably, rice possesses the ability to germinate in anoxic environments, a characteristic deemed crucial for the successful establishment of this crop (Miro *et al,*2017). Under anoxic conditions, deepwater rice exhibited significantly higher and more rapid germination compared to aerobic conditions (Kumari *et al,* 2022).A study was conducted involving the collection of 94 DWR genotypes from various flood-occuring regions of Assam, utilizing an association mapping strategy to identify significant SNPs and genes pertinent to DWR. These rice genotypes are recognized for their distinctive capability to elongate under such conditions. Genome-wide association studies (GWAS) were performed using a 50 K rice genic SNP chip across the 94 genotypes. Analysis of population structure and diversity indicated that these genotypes were categorized into four distinct subpopulations. Through the GWAS approach, 20 significant genes associated with traits related to anaerobic germination were identified. Among these, two particularly relevant genes, OsXDH1 and SSXT were pinpointed as contributors to phenotypic variability within the population. These genes are situated on chromosome 3 and chromosome 12 respectively. Both genes were involved with the anaerobic response index, specifically in coleoptile length increase under anaerobic conditions compared to the control conditions. The genes associated with anaerobic germination traits identified in the study can serve as valuable resources for rice breeding, particularly in regions susceptible to flooding (Rohilla *et al,* 2020).

Conservation of the Germplasm

The National Rice Research Institute (NRRI) has successfully gathered approximately 126 accessions of Bao rice germplasm from the deep water regions of Assam and Meghalaya, which have been assessed for their potential use in breeding programs. These germplasm materials are characterized, harvested, processed, packaged, and dispatched to the National Gene Bank for long-term preservation. Additionally, a subset of these materials is conserved at ICAR-NRRI under suitable storage conditions (Patra *et al,* 2018). The Zonal/Regional Agricultural Research Station (ZARS/RARS) of North Lakhimpur, which serves as the zonal research station for the North Bank Plains Zone under Assam Agricultural University (AAU), has successfully developed and recommended numerous deep water rice varieties for agricultural cultivation through various breeding initiatives. The station has gathered and preserved a total of 231 local landraces alongside exotic deep water rice germplasm, which are maintained on-site. Several cultivars have been created through pure-line selection, including LPR 245, LPR 345, and LPR 85, specifically for regions prone to stagnant flooding, as well as through hybridization, resulting in varieties such as Padmanath, Panindra, and Panchanan (Chowdhury, 2023).However, currently ZARS is conserving 245 germplasms of Deep Water Rice (Dr. Y. Das, Personal communication, 21 February, 2025). Conservationists are finding ways for protecting the novel genes through various molecular breeding approaches. However, conservation practicality is always a challenging task for traditional seeds due to their low viability in nature. One traditional DWR cultivar TNR1 (Thalainayar 1) collected from Agriculture Extension Centre, Thalainayar village of Nagapattinam, India with antidiabetic, salinity as well as submergence resistance properties was reported for the first time to be protected using callus induction and regeneration system from possible extinction (Rameshkumar, 2019).

Conclusion

Deep water rice varieties exhibit remarkable resilience to water-logged conditions, allowing them to survive or adapt during flooding, as such presents significant advantages for rice-growing regions that experience flooding. This particular variety has developed adaptive strategies to either evade or endure conditions of deep water-logging. Its morphological and anatomical features, including the emergence of adventitious roots from upper nodes, elongated internodes, and the presence of aerenchyma in the roots, have enabled the plant to thrive in submerged environments.The distinctive genetic composition of the plant has enabled it to both germinate as well as thrive in prolonged periods of flooding.These varieties are enriched with various nutritional value and antioxidant properties. However, one significant issue in cultivation is its low yield, which can be attributed to the majority of varieties lacking high-yielding traits. A viable approach would involve transferring desirable traits from high-yielding, popular genotypes to traditional genotypes, in conjunction with the integration of genes that confer tolerance to biotic stresses. Therefore, biofortification of deep water rice is much needed as it is the only rice variety that serves as the subsistence crop for the indigenous people of Assam.

Declaration: The authors declare that they do not have any conflict of interest.

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