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Boro rice cultivation practices and adaptive strategies of farmers to flash floods in Sylhet haor basin

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Abstract

Flash floods significantly threaten agricultural livelihoods in the Sylhet Haor Basin of Bangladesh, particularly impacting Boro rice cultivation. This study examines the cultivation practices and adaptive strategies that Haor farmers employ in response to these flood risks. A questionnaire survey was conducted with 298 farmers from both highly and moderately flash flood–vulnerable zones between November 2021 and April 2022. The findings reveal that farmers largely rely on traditional practices and cultivate a mix of modern, local, and hybrid rice varieties, showing limited adoption of improved agronomic methods. Key constraints to boro rice production include early-season flash floods, cold stress, the unavailability of short-duration high-yielding varieties, and inadequate irrigation infrastructure. To cope with these challenges, farmers have implemented several adaptive strategies, such as cultivating short-duration rice varieties, transplanting early and aged seedlings, diversifying rice varieties, harvesting at around 80% maturity, and preparing raised seedbeds. However, the effectiveness and application of these strategies vary depending on the level of flood vulnerability. Farmers emphasized the importance of rice varieties that are short-duration, cold-tolerant, and resistant to submergence, along with improved agronomic practices. The study recommends targeted breeding programs, robust seed systems, enhanced extension services, and infrastructure development. Additionally, integrating local knowledge into national agricultural planning is crucial to strengthen the long-term climate resilience of boro rice farming in the flood-prone Haor region. These insights are valuable for researchers, policymakers, and development practitioners aiming to enhance sustainable rice production in vulnerable Haor ecosystems.

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Introduction

The Sylhet Haor Basin, a vast floodplain wetland ecosystem in northeastern Bangladesh, is vital in sustaining agricultural economy and food security (Kamruzzaman and Shaw, 2018). Covering approximately 0.29 million hectares of net cultivable land, the Haor region contributes significantly to national rice production, yielding over 5.25 million tons of rice annually and representing nearly 16% of the total rice cultivation area in the country (Rahman, 2019). Despite this substantial contribution, agricultural activities in the Haor Basin are increasingly threatened by climatic variability and the unique hydrological features of the basin. Flash floods in April and May severely limit many year-round crops, including dry-season boro rice.

During the dry season (rabi), when water recedes, the region becomes suitable for boro rice, the primary crop in the Haor Basin. Boro rice cultivation, which relies heavily on irrigation from adjacent water bodies and benefits from the high moisture-retention properties of soils , has become the backbone of food production in this season (Azmeri and Isa, 2018). However, pre-monsoon flash floods, frequently occurring from mid-April to early May, pose a grave threat to boro rice cultivation. Triggered by erratic local rainfall and intense upstream runoff from the surrounding hill ranges of Assam and Meghalaya, these floods often lead to catastrophic crop losses and disruption of rural livelihoods (Akter *et al.*, 2022; Islam, 2017).

The unique hydrology of the Haor Basin ensures that much of the area remains submerged for nearly half the year, except for elevated homestead lands. Consequently, the cultivation window is limited to the rabi season, during which boro rice becomes the primary crop. While irrigation is necessary due to minimal rainfall during this period, boro rice's sensitivity to unseasonal inundation makes it highly vulnerable (Islam, 2016). The recurrence of flash floods during the crop's ripening stage results in widespread damage, pushing marginal farmers into cycles of debt and food insecurity (Uddin *et al.*, 2019). In an already subsistence-based farming system characterized by low yields and minimal capital investment, the increasing unpredictability of weather events exacerbates farmers' vulnerability (Hassan and Das, 2015).

In response, local farmers employed a combination of traditional knowledge and emerging technologies to manage the risks associated with flash floods. Although the outcomes vary, these adaptive behaviors are obvious to sustaining agricultural productivity and safeguarding livelihoods in the face of climate-induced hazards (Sumon and Islam, 2013). Farmers in the Sylhet Haor Basin are increasingly adopting altered planting times, short-duration rice varieties, and floating seedbeds to cope with flash floods (Baten *et al.*, 2018). Despite limited institutional support, these farmer-driven innovations reflect evolving responses to climate shocks. However, early warning systems and flood forecasting remain inadequate for timely flash flood prediction (Kazal *et al.*, 2017). As a result, community-led adaptation remains the most practical strategy to reduce impacts.

Farmers rely largely on indigenous knowledge, communal practices, and low-cost innovations to protect boro rice fields from inundation (Abedin and Khatun, 2019). Still, the Boro-based livelihood system remains vulnerable and urgently needs robust protection measures (Bari and Husna, 2023). Coping strategies, such as elevated seedbeds, revised crop calendars, cropping system diversification, and awareness building h have been adapted to varying degrees. Yet, their effectiveness and scope remain under-researched. There is limited empirical understanding of how farmers in the Sylhet Haor Basin manage boro cultivation under recurrent flash floods. The specific techniques used, adoption motivations, and influencing socioeconomic and environmental factors are not well documented. Understanding these elements is crucial for designing targeted interventions. This study aims to explore boro rice cultivation practices and assess the adaptive strategies employed by farmers facing flash flood risks based on the premise that integrating traditional and modern methods enhances resilience.

Materials and methods

Study area

The study was carried out from November 2021 to April 2022 across nine Haor districts. A multistage sampling approach was employed to randomly select a total of 298 farmers, following the methodology suggested by Etikan and Bala (2017). The sample comprised 144 farmers from areas classified as moderately vulnerable to flash floods and 154 farmers from highly vulnerable zones (Fig. 1). Field sites were selected from several unions within the districts of Sylhet (Companyganj, Gowainghat, Jaintiapur, Zakiganj), Sunamganj (Jamalganj, Tahirpur, South Sunamganj), and Kishoreganj (Itna, Mithamoin), which are considered highly susceptible to flash floods. In addition, unions from seven upazilas across Brahmanbaria (Nabinagar, Nasirnagar), Kishoreganj (Austagram, Nikli), and Maulvibazar (Barlekha, Kulaura, Maulvibazar Sadar) were included to represent areas with moderate vulnerability. To ensure spatial accuracy and support mapping efforts, GPS coordinates were recorded for each participating farmer (Fig. 1).

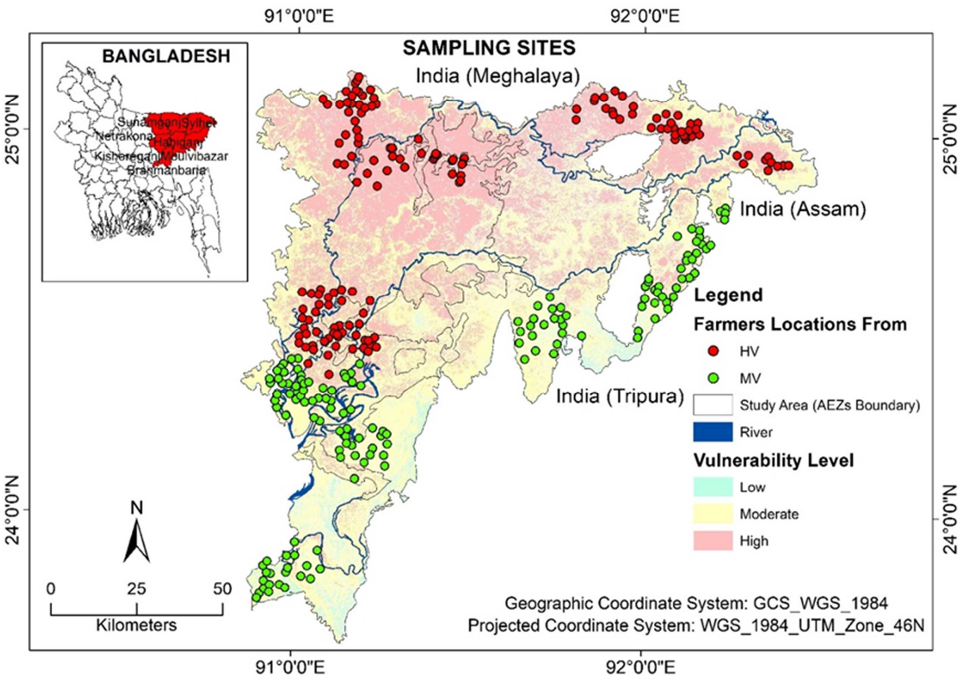

Fig. 1. A map showing the locations of selected farmers at various parts of the Sylhet Haor Basin, categorized by different levels of flash flood vulnerability. Farmers from moderately vulnerable areas are marked with green circles labeled MV, while those from highly vulnerable areas are indicated by red circles labeled HV.

Selection of survey areas: high and moderate flash flood vulnerability zones

Survey locations within the Sylhet Haor Basin were selected based on their susceptibility to flash floods. A prior analysis (unpublished) employed the Analytical Hierarchy Process (AHP), a multi-criteria decision-making method within a Geographic Information System (GIS) framework, to identify areas with varying degrees of flash flood vulnerability. This assessment considered several flash flood-inducing indicators and indices. Based on the results, sites categorized as highly or moderately vulnerable were chosen for data collection. Areas classified as having low vulnerability were excluded due to their limited spatial extent.

Questionnaire survey and data collection

Primary data were collected through face-to-face interviews with farmers using a structured household-level questionnaire. In addition, secondary information was obtained from official documents, research journals, reports, and other relevant literature. The questionnaire was initially pre-tested under actual field conditions and revised accordingly to ensure clarity and relevance. It was then finalized following a consultation meeting with stakeholders and in-depth discussions with subject matter experts. During the interviews, particular emphasis was placed on understanding farmers' practices in boro rice cultivation, the major challenges they face in the Haor region, and their adaptive strategies for managing boro rice under flash flood risks. The survey also explored potential breeding and agronomic management options to enhance the resilience of boro rice against flash flood hazards.

Index score calculation and ranking method

To assess the severity of each issue, an index score was calculated by multiplying the frequency of responses in each category by its assigned weight. The weighted values across all response categories (cells) were then summed to obtain a final index score for each issue. Based on these scores, issues were ranked—higher index scores indicated higher severity and thus received a higher rank.

Analytical approach

Data analysis was conducted using SPSS software (version 24). Descriptive statistics such as frequency and percentage were used to summarize and interpret the collected data. These values were employed to identify patterns and trends relevant to the study objectives.

Results and discussion

Boro rice cultivation practices in the haor region

In the Sylhet Haor region, approximately 80% of arable land is dedicated to boro rice cultivation. This area is submerged under 5 to 10 meters of water from late May to October (Akter *et al.*, 2022). Survey findings indicate that farmers in highly flash flood-prone zones cultivate a mix of modern high-yielding varieties (MVs), local varieties (LVs), and hybrid varieties (HVs) during the rabi season. Common MV varieties in these high-risk areas include BRRI dhan28 and BRRI dhan29. Popular LVs include Birun, Gochi, Lakhai, Tepi, and Khoiya. Frequently grown HVs in this region are Jhalak, American 14, Hira 2, JanakRaj, and Gazi 14. In moderately vulnerable zones, farmers primarily cultivate MVs and LVs, also growing BRRI dhan28 and BRRI dhan29 as MVs, while Poshurail, Tepi, and Mongol are commonly grown as LVs. Regardless of the level of vulnerability, farmers in the Haor region adapt their cultivation practices based on local environmental conditions and experience, as reported by Alam *et al.* (2010).

Seedbed sowing and transplanting schedule

The schedules for seedbed preparation and transplanting vary depending on the rice variety and location (Table 1). In areas highly prone to flooding, modern varieties like BRRI dhan28 and BRRI dhan29 are typically shown between November 10 and December 16. In areas with moderate flood risk, sowing begins earlier, from October 28 to November 30. For local rice varieties, seedbed sowing in high-risk zones usually takes place between November 10 and November 30. In moderately vulnerable areas, this period extend from October 31 to November 30. Transplanting times also differ based on the variety and specific site conditions. The differences in sowing and transplanting schedules are primarily influenced by the topography and soil characteristics of the Haor Basin, which affect the timing of floodwater recession after the monsoon. As a result, boro rice cultivation typically starts earlier in moderately vulnerable areas compared to those with highly vulnerable (Adnan *et al.*, 2019).

Transplanting method

Transplanting is the most widely used method for establishing boro rice in the Haor region. Haor farmers generally transplant seedlings from seedbeds into puddled and leveled fields. The most common practice observed is random transplanting (Table 2), which farmers prefer because it is less time-consuming than line transplanting or mechanized methods. However, even when line transplanting is practiced, recommended spacing guidelines are often not followed, leading to suboptimal plant population and yield. Details of transplanting methods by variety and location are provided in Table 2.

Table 1. Timing of seedbed planting and transplanting of various boro rice cultivars in areas with high and moderate risk of flash floods

Type of variety	Name of the variety	Seedbed sowing time		Transplanting time	
		Highly vulnerable zone	Moderately vulnerable zone	Highly vulnerable zone	Moderately vulnerable zone
MV	BRRI dhan28	Agrahayan 1 - Beginning of Poush (16 Nov-16 Dec)	Kartik 12 - Agrahayan 15 (28 Oct-30 Nov)	Poush 10 - Magh 15 (25 Dec-29 Jan)	Agrahayan 15 - Poush 20 (30 Nov-04 Jan)
	BRRI dhan29	Kartik 25 - Agrahayan 20 (10 Nov-05 Dec)	Kartik 12 - Beginning of Agrahayan (28 Oct-16 Nov)	Agrahayan 30 - Poush 30 (15 Dec-14 Jan)	Agrahayan 15 - Beginning of Poush (30 Nov-16 Dec)
LV	Birun	Kartik 25 - Agrahayan 15 (10-30 Nov)	-	2nd week of Poush (23-29 Dec)	-
	Gochi	Kartik 25 - Agrahayan 15 (10-30 Nov)	-	2nd week of Poush (23-29 Dec)	-
	Lakhai	Kartik 25 - Agrahayan 15 (10-30 Nov)	-	2nd week of Poush (23-29 Dec)	-
	Tepi	Kartik 25 - Agrahayan 15 (10-30 Nov)	Kartik 15 - Beginning of Agrahayan (31 Oct-16 Nov)	Poush 25-30 (09-14 Jan)	Agrahayan 25 - Beginning of Poush (10-16 Dec)
	Khoiya	Kartik 25 - Agrahayan 15 (10-30 Nov)	-	Poush 25-30 (09-14 Jan)	-
	Poshurail	-	Kartik 15 - Agrahayan 15 (31 Oct-30 Nov)	-	1st week of Poush (16-22 Dec)
	Mongol	-	Kartik 15 - Beginning of Agrahayan (31 Oct-16 Nov)	-	1st week of Poush (16-22 Dec)
Hybrid	Jhalak	1st week of Agrahayan (16-22 Nov)	-	2nd week of Poush (23-29 Dec)	-
	American 14	1st week of Agrahayan (16-22 Nov)	-	2nd week of Poush (23-29 Dec)	-
	Hira 2	1st week of Agrahayan (16-22 Nov)	-	2nd week of Poush (23-29 Dec)	-
	JanakRaj	Agrahayan 16-20 (01-05 Dec)	-	Poush 20-30 (04-14 Jan)	-
	Gazi 14	Agrahayan 25-30 (10-15 Dec)	-	Poush 30 - Magh 15 (14-29 Jan)	-

Note: Total number of respondents (n = 298). There were 154 responders from high-risk flash flood zones and 144 from moderate-risk zones. MV: modern variety; LV: local variety

Table 2. Transplanting method of various boro rice cultivars in areas with high and moderate risk of flash floods

Type of variety	Name of the variety	Transplanting method	
		Highly vulnerable zone	Moderately vulnerable zone
MV	BRRI dhan28	Random Line (14x15 cm; 15x15 cm; 15x17 cm; 16x15 cm; 16x16 cm; 17x15 cm; 17x17 cm; 18x18 cm)	Random Line (15x15 cm; 17x17 cm; 19x19 cm).
	BRRI dhan29	Random Line (12x12 cm; 14x15 cm; 15x15 cm; 17x16 cm; 17x17 cm; 18x18 cm)	Random Line (15x15 cm; 17x17 cm; 18x18 cm)
LV	Birun	Random	-
	Gochi	Random	-
	Lakhai	Random	-
	Tepi	Random	Random
	Khoiya	Random	-
	Poshurail	-	Line (15x15 cm)
	Mongol	-	Line (17x17 cm)
Hybrid	American 14	Line (15x15 cm; 18x15 cm)	-
	Hira 2	Random Line (15x15 cm)	-
	JanakRaj	Line (17x17 cm)	-
	Gazi 14	Line (17x17 cm; 19x19 cm)	-

Note: Total number of respondents (n = 298). There were 154 responders from high-risk flash flood zones and 144 from moderate-risk zones. MV: modern variety; LV: local variety.

Challenges faced by Haor farmers in boro rice cultivation

Major constraints to boro rice cultivation

Farmers in the Haor region face several challenges when cultivating boro rice, especially in areas prone to flash floods. According to a survey, the top five challenges identified are flash floods, cold stress, a lack of desirable short-duration and high-yielding rice varieties, limited availability of quality seeds at the local level, and insufficient irrigation water. These issues are common across both highly and moderately flash flood-prone areas (Table 3a&b). Farmers also reported additional problems such as the lack of harvesting mechanization, inefficient market value chains, and the rising cost of fertilizers. In highly vulnerable zones, flash flooding was viewed as the most severe constraint, followed by the shortage of suitable short-duration high-yielding cultivars. In contrast, in moderately vulnerable areas, the lack of appropriate short-duration high-yielding varieties is ranked highest, followed by cold stress, and then flash floods.

Table 3a. Rank order of problems faced by the haor farmers during boro rice cultivation in areas with high risk of flash floods

Constraints	Highly vulnerable zone					Index score	Rank
	Levels of problem						
	Not at all a problem (0)	Minor problem (1)	Moderate problem (2)	Very much problem (3)	Serious problem (4)		
Major climatic hazard: flash flood	-	-	-	22.7	77.3	581	1st
Major climatic hazard: cold stress	-	5.2	24.0	53.2	17.5	436	4th
Lack of desirable short-duration high high-yielding boro rice varieties	-	-	1.3	81.2	17.5	487	2nd
Inadequate availability of rice seeds (improved and HYV) at local level	-	-	3.2	80.5	16.2	482	3rd
Scarcity of irrigation water	11.0	4.5	15.6	40.3	28.6	417	5th
Lack of mechanization of crop harvesting	5.2	8.4	29.2	50.6	6.5	377	6th
Market value chain	1.3	9.1	44.8	39.6	5.2	367	7th
High cost of fertilizer	3.9	14.9	40.3	37.0	3.9	342	8th

Table 3b. Rank order of problems faced by the Haor farmers during boro rice cultivation in areas with moderate risk of flash floods

Constraints	Moderately vulnerable zone					Index score	Rank
	Levels of problem						
	Not at all a problem (0)	Minor problem (1)	Moderate problem (2)	Very much problem (3)	Serious problem (4)		
Major climatic hazard: flash flood	0.7	10.4	41.0	41.0	6.9	350	3rd
Major climatic hazard: cold stress	-	-	-	75.0	25.0	468	2nd
Lack of desirable short-duration high high-yielding boro rice varieties	-	-	1.4	68.1	30.6	474	1st
Inadequate availability of rice seeds (improved and HYV) at local level	17.4	11.1	31.3	27.8	12.5	298	4th
Scarcity of irrigation water	-	-	98.6	-	1.4	292	5th
Lack of mechanization of crop harvesting	18.8	32.6	14.6	13.2	20.8	266	6th
Market value chain	1.4	43.1	28.5	25.0	2.1	264	7th
High cost of fertilizer	14.6	29.2	34.7	13.9	7.6	246	8th

Note: Total number of respondents (n = 298). There were 154 responders from high-risk flash flood zones and 144 from moderate-risk zones. Scales of 0 to 4 represent different levels of the problem. Each "level of problem" has values that represent the proportion of responders. A five-point rating system was used by farmers to rank various issues: 0 meant not at all a problem; 1 meant minor problem; 2 meant moderate problem; 3 meant very much problem; and 4 meant serious problem. Lastly, each problem's index score was determined using the following formula: index score = (number of respondents × 0) + (number of respondents × 1) + (number of respondents × 2) + (number of respondents × 3) + (number of respondents × 4).

Limitations of early transplanting and seed supply

Haor farmers are generally advised to transplant boro seedlings earlier than usual to reduce the risk of yield loss from late-season flash floods (Biswas *et al.*, 2008). Early transplanting also enables them to take advantage of the timely recession of residual floodwaters. However, this strategy brings its own risk: early-transplanted boro rice is more vulnerable to low temperatures during its reproductive stage, which can lead to increased spikelet sterility and decreased yields (Rashid and Yasmeen, 2017). Another significant issue is the inadequate supply of improved seeds. The Bangladesh Agricultural Development Corporation (BADC) cannot meet the demands for high-yielding varieties due to limited production capacity and a weak distribution network. Currently, BADC's seed distribution system consists of only two regional centers, five district-level centers, and two upazila-level offices, which is insufficient to serve the extensive Haor region (CEGIS, 2012).

Irrigation challenges and sedimentation issues

A significant limitation to the expansion of boro rice cultivation in the Haor Basin is the lack of adequate irrigation infrastructure. Heavy monsoon rains in the nearby Indian hills wash down coarse materials, including boulders and large stones, which are accumulate in riverbeds and the Haor basin. Over time, this sediment buildup raises the wetland beds, disrupts natural water flow and leads to water shortages during the dry season, when irrigation is most crucial for boro cultivation (Hoq *et al.*, 2021).

Adaptive strategies adopted by haor farmers to cope with flash floods

Farmers' response to flash flood risks

Due to their vulnerability to recurring flash floods, Haor farmers have developed several adaptive strategies to reduce crop losses, especially during the boro rice growing season. These strategies have evolved through years of experience and experimentation under local field conditions. Although the effectiveness of these measures varies with location and context (Smit and Wandel, 2006), farmers have consistently identified six key practices for mitigating flash flood damage during both premature and mature growth stages of boro rice. These practices include cultivating short-duration high-yielding boro rice varieties, adjusting the transplanting time of rice seedlings, practicing varietal diversification, transplanting aged seedlings, harvesting rice at 80% maturity and using raised seedbeds during waterlogged conditions (Table 4a&b).

Categorization and ranking of adaptation practices

The adaptation strategies were ranked according to the adoption scores of farmers. In areas highly vulnerable to flash floods, the most commonly adopted strategy was harvesting rice at 80% maturity, followed by growing short-duration high-yielding variety (HYV) rice, varietal diversification, and transplanting aged seedlings. The strategies of early transplanting and the use of raised seedbeds were the least adopted. In moderately vulnerable zones, the preferred strategy was cultivating short-duration HYV boro rice, followed by early harvesting, varietal diversification, early transplanting, transplanting aged seedlings, and finally the use of raised seedbeds.

Early harvesting at 80% maturity

Due to the increasingly early arrival of flash floods, especially in high-risk areas (Akter *et al.*, 2022), many farmers have started harvesting their rice when it reaches approximately 80% maturity. This practice has become common to prevent total crop loss, although it may necessitate localized early warning systems to improve timing and manage risks more effectively (Herath and Thirumarpan, 2017).

Cultivation of short-duration HYV boro rice

In moderately vulnerable zones, one of the most effective adaptation strategies has been the cultivation of short-duration high-yielding boro rice varieties. These varieties mature earlier and are less susceptible to early flash floods, with BRRI dhan28 being a popular choice. Research indicates that recent changes in flood timing, often occurring in March instead of May, have made adopting this strategy even more critical (Hossain *et al.*, 2023; Pinaki *et al.*, 2017).

Table 4a. Rank order of flash flood coping adaptive strategies adopted by the Haor farmers for securing boro rice production against flash floods (Highly vulnerable zone)

Adaptive strategy	Highly vulnerable zone				Adoption index	Rank
	Adoption category					
	No (0)	Low (1)	Moderate (2)	Full (3)		
Shifting harvesting period of rice at 80% maturity	-	-	58.4	41.6	372	1st
Cultivating existing short-duration high high-yielding boro rice varieties	0.6	1.3	55.2	42.9	370	2nd
Practicing varietal diversification	-	-	66.2	33.8	360	3rd
Transplantation of aged seedlings	-	13.0	48.1	39.0	348	4th
Early transplanting of rice seedlings	2.6	11.0	46.1	40.3	345	5th
Use of raised seedbed for raising seedlings	-	-	91.6	8.4	321	6th

Table 4b. Rank order of flash flood coping adaptive strategies adopted by the Haor farmers for securing boro rice production against flash floods (Moderately vulnerable zone)

Adaptive strategy	Moderately vulnerable zone				Adoption index	Rank
	Adoption category					
	No (0)	Low (1)	Moderate (2)	Full (3)		
Shifting harvesting period of rice at 80% maturity	-	-	54.2	45.8	354	2nd
Cultivating existing short-duration high high-yielding boro rice varieties	-	1.4	50.7	47.9	355	1st
Practicing varietal diversification	-	-	57.6	42.4	349	3rd
Transplantation of aged seedlings	-	-	84.0	16.0	311	5th
Early transplanting of rice seedlings	-	-	78.5	21.5	319	4th
Use of raised seedbed for raising seedlings	1.4	6.3	76.4	16.0	298	6th

Note: Total number of respondents (n = 298). There were 154 responders from high-risk flash flood zones and 144 from moderate-risk zones. Scales of 0 to 3 represent different adoption categories. Each "adoption category" has values that represent the proportion of responders. A four-point rating system was used by farmers to rank various adaptive strategies: 0 meant no; 1 meant low; 2 meant moderate; and 3 meant full. Lastly, each adaptive strategy's index score was determined using the following formula: index score = (number of respondents × 0) + (number of respondents × 1) + (number of respondents × 2) + (number of respondents × 3).

Practicing varietal diversification

Varietal diversification is a key adaptation strategy that ranks third among all vulnerability zones. Farmers adopt a mix of rice varieties with different maturity periods to mitigate the risk of crop loss. For instance, they combine long-duration HYV, such as BRRI dhan29, with short-duration varieties like BRRI dhan28 or traditional ones such as Tepi, Guchi, Lakhai. Although traditional varieties may yield less, they can be harvested before the typical onset of flash floods in early May (Islam, 2017; Alam *et al.*, 2010).

Early and aged seedling transplanting, and raised seedbeds

Other adaptation practices include early transplanting, the use of aged seedlings, and the preparation of raised seedbeds. Aged seedlings can slightly shorten the crop duration, helping to avoid damage from flash floods, though they may reduce yield if not properly managed (Herath and Thirumarpan, 2017; Salam *et al.*, 1995). Early transplanting enables harvesting before floodwaters arrive, but effective drainage is crucial for the success of this method. Raised seedbeds offer protection for seedlings during waterlogging and allow for timely transplanting after water levels recede (Dey *et al.*, 2017). While these methods are less common, they show promise under specific farming conditions in the Haor region.

Managing flash flood hazards: breeding and agronomic solutions

Flash floods during the maturity stage and cold stress during the reproductive phase are the two most critical challenges affecting boro rice yield in the Haor region (Rashid and Yasmeen, 2017). To address these issues, Haor farmers were consulted to identify and prioritize breeding and agronomic strategies that could help mitigate the risks associated with flash flood events.

Priority for developing cold-tolerant, short-duration varieties

Farmers in flash flood-prone zones expressed an urgent need for the development of short-duration (100–105 days), high-yielding, and cold-tolerant rice varieties (Table 5a&b). These varieties would enable harvesting before the onset of early flash floods. Scientists of Bangladesh Rice Research Institute (BRRI) emphasized the importance of incorporating cold tolerance into early-maturing rice lines. This recommendation aligns with findings by Bhuiyan *et al.* (2020), further reinforcing the necessity for targeted varietal improvement. Cold damage to boro rice, particularly during the dry season, is a significant issue in Haor areas that are prone to early flooding (BRRI, 2016). When boro rice is transplanted at the usual time, it can avoid cold stress during reproduction but becomes vulnerable to flash floods at maturity (Biswas *et al.*, 2008). Conversely, early transplanting helps prevent flooding but increases the risk of cold stress during the reproductive stage, especially from panicle initiation to flowering, which can lead to higher rate of spikelet sterility (Biswas *et al.*, 2011).

Table 5a. Prioritizing breeding and agronomic management options for managing flash flood hazards on boro rice production in areas with high risk of flash floods (farmer's priority)

Breeding and agronomic management options	Highly vulnerable zone						
	Priority level						
	Not a priority (0)	Low (1)	Medium (2)	High (3)	Essential (4)	Index score	Rank
Short-duration (100-105 days) high-yielding cold-tolerant boro rice varieties	-	-	-	20.8	79.2	584	1st
Taller, short duration, submergence tolerance at the late reproductive stage, and non-shattering variety	-	-	-	31.2	68.8	568	2nd
Timely sowing and transplanting	-	-	-	51.9	48.1	536	3rd
Manipulation of seedling age	-	-	-	66.9	33.1	513	4th
Direct wet seeding of rice	-	-	1.9	79.2	18.8	488	5th

Table 5b. Prioritizing breeding and agronomic management options for managing flash flood hazards on boro rice production in areas with moderate risk of flash floods (farmer's priority)

Breeding and agronomic management options	Moderately vulnerable zone						
	Priority level						
	Not a priority (0)	Low (1)	Medium (2)	High (3)	Essential (4)	Index score	Rank
Short-duration (100-105 days) high-yielding cold-tolerant boro rice varieties	-	-	-	25.7	74.3	539	1st
Taller, short duration, submergence tolerance at the late reproductive stage, and non-shattering variety	-	-	-	30.6	69.4	532	2nd
Timely sowing and transplanting	-	-	-	54.2	45.8	498	3rd
Manipulation of seedling age	-	-	20.8	43.8	35.4	453	4th
Direct wet seeding of rice	-	-	8.3	69.4	22.2	452	5th

Note: Total number of respondents (n = 298). There were 154 responders from high-risk flash flood zones and 144 from moderate-risk zones. Scales of 0 to 4 represent different levels of priority. Each "level of priority" has values that represent the proportion of responders. A five-point rating system was used by farmers to prioritize the said breeding and agronomic options for managing flash flood hazards on boro rice production: 0 meant not a priority; 1 meant low priority; 2 meant medium priority; 3 meant high priority; and 4 meant essential. Lastly, each breeding and agronomic option's index score was determined using the following formula: index score = (number of respondents × 0) + (number of respondents × 1) + (number of respondents × 2) + (number of respondents × 3) + (number of respondents × 4).

Desired traits in improved varieties

Farmers have emphasized the importance of developing rice varieties with specific beneficial traits, which they rank as the second priority. These traits include taller plant heights to reduce the risk of submergence, shorter growth duration, submergence tolerance during the late reproductive phase, and non-shattering grain characteristics. These features are critical in preventing yield loss caused by pre-flood events such as heavy rains and hailstorms (Neelima *et al*., 2015).

Agronomic adjustments for risk reduction

In addition to improving rice varieties, farmers from both highly and moderately vulnerable Haor areas have highlighted several agronomic practices that can help mitigate flood-related damage. Timely sowing and transplanting are ranked as the third priority, as they are essential for aligning crop maturity with the safe harvesting window. Manipulating seedling age, ranked fourth, provide flexibility in crop scheduling, which helps reduce exposure to flood or cold risks. The adoption of direct-seeded rice is ranked fifth. This method effectively shortens the crop cycle, allowing farmers to harvest 10 to 12 days earlier than traditional transplanting methods. By sowing seeds directly into the land right after the floodwaters recede, farmers can cultivate Boro crops earlier, enabling the crops to ripen before potential flash floods. This approach is particularly beneficial for haor regions (Rahman, 2019).

Conclusion

The study shows that Haor farmers cultivate a diverse range of rice varieties, including modern, local, and hybrid types, mainly guided by traditional knowledge and with limited use of modern agricultural practices. The main challenges faced in Boro rice production include early flash floods, a lack of short-duration high-yielding varieties, cold stress during the reproductive stage, and inadequate irrigation facilities. Despite these obstacles, farmers actively implement various adaptive strategies such as early planting, using older seedlings, harvesting at around 80% maturity, varietal diversification, and adopting relatively short-duration high-yielding varieties that have proven effective. These strategies depend on the level of flash flood risk, location conditions, and available resources.

Farmers urgently need for improved rice varieties that have a short growth duration, cold tolerance, and waterlogging resistance to better manage climate-related challenges, particularly flash floods. To address these needs, the study emphasizes the importance of collaboration between farmer-led innovations and government-supported research. Key recommendations include increasing the availability of improved seeds, strengthening agricultural extension services, upgrading drainage and irrigation infrastructure, and integrating indigenous knowledge into research and agricultural planning. The findings of this study can guide policy development and strategic actions aimed at protecting Boro rice cultivation from flash floods while enhancing livelihoods and food security in the Haor region of Bangladesh.

Policy implications

Effective policy steps need to be taken to ensure the viability of boro rice cultivation in flash flood-prone Haor Basins. First, breeding efforts should focus on developing short-lived, cold-tolerant, and waterlogging-resistant rice varieties. Second, to ensure timely availability of quality seeds, local seed distribution networks need to be strengthened, particularly through public-private collaboration. Third, it is essential to increase region-specific extension services and farmer training, to support adaptive practices such as early or aged seeding transplanting, use of raised seedbeds, and varietal diversification. Fourth, drainage and irrigation infrastructure needs to be improved to facilitate timely agricultural activities and reduce the risk of waterlogging. Finally, it is crucial to integrate indigenous adaptation knowledge into national agricultural and climate policies so that these interventions are contextually relevant and widely adopted.

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