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RESEARCH ARTICLE

Perception of and adaptation to climate change: the case of wheat farmers in northwest Bangladesh

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Abstract
Climate change's impact on crop production is a global concern. A better understanding of farmers' perceptions of climate change and adaptation strategies will benefit farmers and policymakers in outlining an effective adaptation mechanism to climate change. Therefore, this study assessed wheat farmers' perceptions of climate change, identified major adaptation strategies, factors influencing adaptations, and barriers to effective adaptation by surveying 160 wheat farmers in northwest Bangladesh. The results revealed that farmers experienced more frequent droughts due to higher temperatures, decreased and irregular precipitation, reduced ground and surface water availability, and shorter winter seasons over the last two decades. Key adaptation strategies identified were more irrigation, switching to other crops, and changing fertilizer and insecticide usage. Multinomial logit model results indicate that farming experience, access to climate information and extension services, access to subsidies, farm size, family size, and electricity for irrigation were the significant factors influencing farmers' adaptation decisions. Limited access to climate information, inadequate knowledge of appropriate adaptation measures, and low price of wheat represented major adaptation barriers. The study recommends strengthening agricultural research and extension services to farmers, including education and training, to develop effective adaptation strategies to climate change.

Keywords Climate change · Perception · Adaptation · Wheat farmers · Bangladesh

Introduction

Agricultural crops are highly reliant on seasonal characteristics and climatic variables such as temperature, rainfall, humidity, and day length (Amin et al. 2015; Sawan 2018; Victor Bekun and Akadiri 2019). Different natural calamities, such as floods, droughts, soil and water salinity, cyclones, and storm surges, also limit the crop's productivity (Abdullah et al. 2019; Jalal et al. 2021; Hossain et al. 2022). Every crop has an ideal temperature range for its vegetative and reproductive stages; therefore, when the temperature goes outside of this range or rises over the top limit, output is curtailed (Hossain and Da Silva 2012; Hatfield and Prueger 2015). The ability for producing wheat is severely hampered by temperature changes since it is cultivated in a cold climatic condition (Musa et al. 2021). As a result, tracing the underlying link between productivity and temperature fluctuation is the first step towards wheat cultivation (Ray et al. 2019). According to a previous study, every 1 °C increase in temperature reduces wheat yields by 6% (Asseng et al. 2014). If no adaptation measures are taken, at least a quarter of the world's wheat crop will be lost due to extreme weather caused by climate change in the next decades (Liu et al. 2016). The effects of anticipated relative temperature on major wheat-producing countries such as China, the USA, India, and France were similar but less for Russia (Liu et al. 2016).

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High temperature causes several alterations in wheat's physiological, biochemical, and molecular components. The ideal temperature for wheat cultivation is approximately 20 °C, ranging between 17 and 23 °C. Plants stop growing below 0 °C or over 37 °C and die at about − 17 °C or 47.5 °C (Porter and Gawith 1999). In Bangladesh, where the lowest temperature is roughly 15° C and the highest temperature is 35° C, however, 20° to 25° C is the ideal temperature for growing wheat (Hossain and Da Silva 2012). In controlled situations, extended daytime and increased temperature during nighttime reduce wheat production (Nuttall et al. 2018). Grain yield is reduced when wheat plants are exposed to daylight temperatures greater than 35 °C during anthesis (Nuttall et al. 2018), whereas nighttime temperatures above 20 °C from the booting to maturity stage of wheat resulted in a decrease in spikelet fertility, grains per spike, grain size, and reduced yield (Prasad et al. 2008). Similar results to high nighttime temperatures have been seen in field settings (García et al. 2015; 2016). Furthermore, the respiration, enzyme activity, vegetation, reproduction, pollen and ovule development, anthesis, grain number, individual grain weight, etc. of wheat crops are all negatively impacted by high temperatures (Narayanan 2018). In the recent decades, Bangladesh's average annual temperature has risen (Mohsenipour et al. 2018; World Bank 2020), particularly in the northwest region (Ahmed and Chowdhury 2006), a major wheat-producing zone. The average annual temperature in Bangladesh was 25.13 °C in 2000 but climb to 25.23 °C in 2020, which possess a severe threat for the growing of several agricultural crops like wheat (World Bank 2022). The northwest region, on the other hand, is predominantly prone to drought and receives significantly less rainfall than the rest of the country, suggesting that the temperature is also higher than other regions of the country (Habiba et al. 2012, World bank 2020). Seasonal drought occurs almost on a regular basis (Murad and Islam 2011). According to a Standardized Precipitation Evaporation Index (SPEI), Bangladesh currently faces an annual likelihood of severe meteorological drought of about 4%, up from about 1% two decades ago (World Bank, 2021). In the years 1991, 1992, 1994, 1995, 1997, 1998, 2000, 2003, 2005, 2007, 2009, 2010, 2012, 2015, 2016, 2018, 2019, and 2021, the northern region of Bangladesh has already experienced severe drought. It is also likely to experience severe drought in the years 2022, 2023, 2024, 2025, and 2026, as well as extreme drought in the years 2023 and 2024 (Afrin et al. 2018; World Bank 2022). As a result, wheat production in these region has been hampered due to these climatic variability (Tasnim et al. 2014). However, the best time to plant wheat in Bangladesh is from 15 to 30 November since the weather is ideal for growing wheat during that time (Jahan et al. 2018).

Wheat consumption is now considered an essential rice complement (Nazu et al. 2021). Wheat has a significant importance in Bangladesh's economy in terms of production, food security, and employment generation. Given that wheat's gross cultivated area in 2021 was 0.328 million ha, which was second only to rice's 28.912 million ha, the production of wheat, on the other hand, is 1.08 million MT, coming in second place to rice (37.61 million MT); thus, it becomes the second-most significant staple food crop after rice (BBS 2021). The Bangladesh government imported wheat to meet the requirements of its rising population and secure future food security (Nazu et al. 2021), and it is probable that imports would provide roughly 88% of the consumption demand (The Daily Star 2022). Precisely, Bangladesh imports 5.8 million MT of wheat in FY 2021 compared to production of 1.08 million MT, and the demand for domestic consumption is expected to increase by around 10 million MT during the following 5 years (Financial Express 2022). In 2022, the country's annual wheat demand stands 7.5 million tonnes, of which 1.1 million tonnes are produced locally and the remaining 6.4 million tonnes are imported from Russia, Ukraine, India, and Canada (Prothom Alo 2022). However, due to farmers' move to producing other crops with greater financial returns such potatoes, vegetables, and Boro rice (Hossain and Teixeira da Silva 2013), domestic output is declining, while consumption is growing; thus, there will be a serious danger to food security if domestic production cannot be increased. Furthermore, climate change-induced global warming has already resulted in a significant shift in Bangladesh's temperature regimes, which has a significant impact on wheat production. Climate change is not the only factor affecting wheat production. There are geophysical factors for which wheat area in the country has become constant or even reduced following the wheat blast in 2016 (Mottaleb et al. 2019). Therefore, wheat production must be increased to meet national demand and reduce import dependency through proper climate change adaptation strategies. Farmers have already developed various farm-level adaptation measures, such as crop rotation, altering the sowing season, etc., as a general survival strategy in the face of changing climate. However, farmers are slow to respond to changes in climatic variables such as rainfall or temperature since they do not confront an immediate severe threat to their farming operations because of these variables (Wood et al. 2014). Furthermore, farmers' lack of understanding of climate change and its impact on wheat production is a barrier to long-term sustainable agriculture in Bangladesh (Kabir et al. 2017). Farmers must first comprehend the issue of climate change and its consequences. Otherwise, they will not be able to choose and put into action appropriate adaptation strategies. Since the majority of Bangladesh's farmers are illiterate or have poor levels of education, they are unaware of the effects of climate change and adaptation measures as it depends not only on perceptions but also on the socio-demographic attributes of the farmers. Against this backdrop, this study investigates wheat farmers' perceptions of and adaptation strategies to climate change in northwest Bangladesh, a critical zone for wheat production.

Many agricultural adaptation strategies have been suggested in various studies, based on different levels (local, regional, global), participants (farmers, farms, governments), and other aspects. The majority of the studies are focused on potential or probable adaptation measures rather than ones that have been actually adopted (Aryal et al. 2020). Several studies in Bangladesh have been conducted to identify the farmers' perceptions of and adaptation measures to climate changes (Alam et al. 2017; Kabir et al. 2017, 2016; Karim and Thiel 2017; Uddin et al. 2017). Some studies also conducted in the northwest region of Bangladesh adaption strategy to combat the climate change (Anik et al. 2021; Al-Amin et al. 2019; Sarker et al. 2013; Habiba et al. 2012, 2014). Rather than focusing on a specific crop, these studies investigated farmers' overall agricultural adaptation tactics, limiting crop-specific adaptation measures. The perceptions of climate change and adaption measure may vary crops to crops, farmers to farmers, and locations to locations since each crop has distinct adaptive capability, each farmer has different perceptions, and each location or regions has identical agroclimatic features. Thus, in order to boost yield for both wheat and other grains, scientists and decision-makers must create climate change adaptation strategies for the sake of farmers' betterment. However, no study has been conducted on the wheat farmers' perception of and adaptation to climate change in Bangladesh to date. In this context, this research attempted to capture the wheat farmers' perceptions and adaptation strategies to climate change in Bangladesh. The study also looks at the obstacles that farmers encounter while adopting the adaptation strategies. Therefore, to promote successful government policy for sustainable cereal production, this study on wheat farmers' perceptions and adaptations to climate change would contribute significantly. The findings would improve our understanding of wheat farmers' perceptions of climate change and adaptation choices, allowing farmers and policymakers to develop better adaptation strategies to mitigate the adverse effect of climate change in Bangladesh.

Material and methods

Study area and data

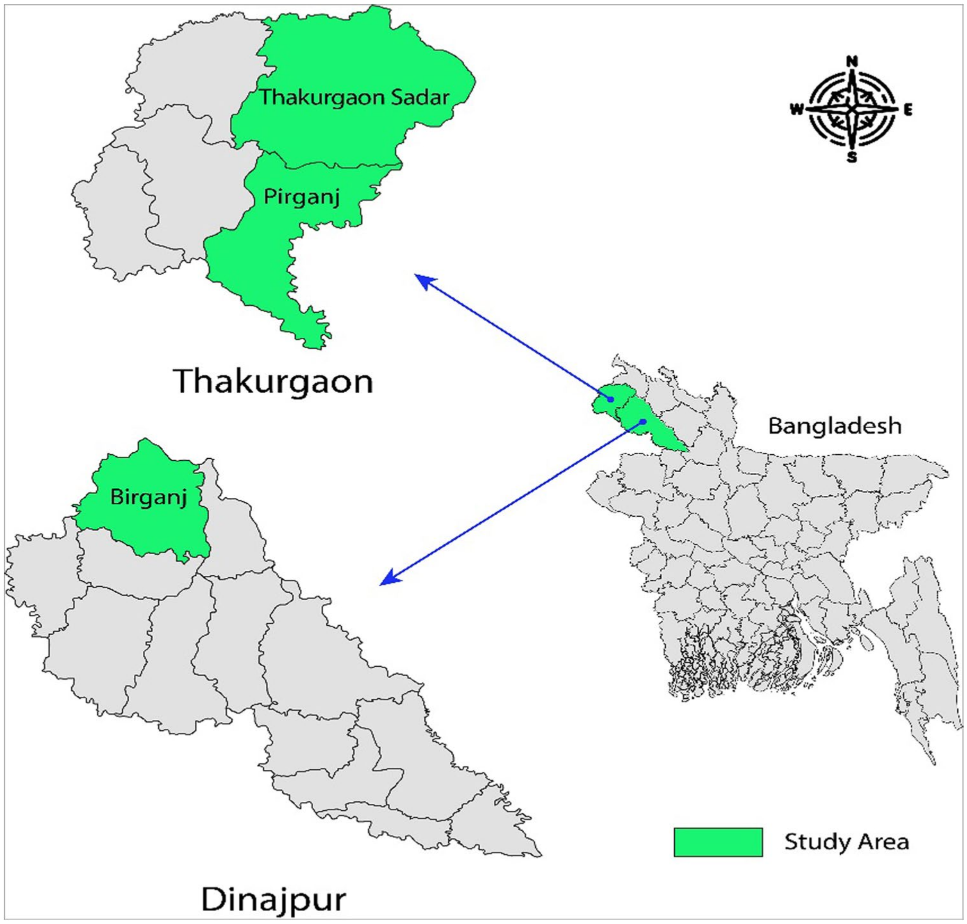
To investigate wheat farmers' perceptions and adaptations to climate change, the study was conducted in the country's climate-vulnerable northwest region. To serve the purpose of this study, a multistage sampling procedure was followed. The total cultivated area under wheat farming in Bangladesh is estimated to be 330,348 ha in FY 2019–2020, and the northwest region occupies around 226,956 ha (68.3%) (BBS 2020). Therefore, two northwestern districts, Dinajpur and Thakurgaon, were selected purposively since they hold a significant share (18.89%) in the national wheat production (BBS 2020). Then, Birganj *Upazila* (sub-district) from Dinajpur and Thakurgaon Sadar and Pirganj *Upazila* from Thakurgaon were selected based on the production of wheat (Fig. 1). Finally, 160 wheat-producing farmers were selected from the list collected from the *Upazila* Agriculture Offices using simple random sampling. The survey was carried out during the wheat harvesting period, from February to March 2019. Face-to-face interviews with respondents were conducted using a structured interview schedule. The interview schedule was developed after an intensive literature review. Farmers were asked various questions regarding their perceptions about different climatic variabilities, causes of climate change, consequences of climatic variabilities, adaptation strategies to climate change, barriers faced to take adaptation strategies, and their socioeconomic status characteristics. Prior to the final survey, the draft survey schedule was pre-tested among a few farmers at the study areas and modified according to the findings to achieve the objectives.

Analytical methods

Multinomial logistic (MNL) regression model for adaptation strategies

This study uses the multinomial logistic (MNL) regression model to analyze the determinants of adaptation strategies. The advantage of the multinomial logistic model is that it permits the analysis of decisions across more than two categories, allowing the determination of choice probabilities for different categories (Wooldridge 2002; Deressa et al. 2009; Saha et al. 2022), and it is also computationally simple (Tse 1987). Furthermore, earlier adaptation studies also used the multinomial logistic model (Alauddin and Sarker 2014; Deressa et al. 2009). By following Deressa et al. (2009) to describe the multinomial logistic model, let y indicate a random variable taking values $\{1, 2, \ldots, J\}$ for J, a positive integer, and let X denote a set of explanatory variables. In this study, y indicates adaptation strategies, and X indicates the factors influencing adaptation strategies such as age, education level of the farmers, family size, farm size, farming experience, access to extension, access to climate information, access to credit, access to subsidies, and availability of electricity for irrigation. The results are expected to reveal how ceteris paribus changes of X influence the response probabilities ($P(y = j/X)$, $j = 1, 2, \ldots, J$). Let X be a $1 \times K$ vector with initial element unity. The MNL model has response probabilities:

Fig. 1 Map of the study area



$$P(y = j|X) = \frac{\exp(X\beta_j)}{[1 + \sum_{h=1}^{J} exp(X\beta_h), j = 1, \ldots \ldots, J]}$$

where β_j is K × 1, j = 1,….., J.

The multinomial logistic model can be regarded as simultaneously estimating binary logits for all possible comparisons among the outcomes. The following equation specifies the multinomial logistic model used for identifying factors influencing farmers' perception in this study.

$$\ln\left[\frac{P_r(y=\frac{1}{x})}{1-P_r(y=\frac{1}{x})}\right] = \ln\ Q\ (x) = \beta_0 + \beta_1 Age + \beta_2 Edu + \beta_3 Exp + \beta_4 Farm_{size} + \beta_5 Family_{size} + \beta_6 Climate_{info} + \beta_7 Exention + \beta_8 Credit + \beta_9 Subsidy + \beta_{10} Electricity + \in_i$$

In the multinomial logit model for adaptation strategies, the age of the farmers was dropped due to the higher likelihood ratio. The adaptation strategies used in our study were six, as described in Table 3. In the multinomial logistic model, the assumption of independence of irrelevant alternatives (IIA) must be satisfied to provide unbiased and consistent properties of parameter estimates. The adaptation strategies in our study were mutually exclusive. Therefore, farmers were asked to select their main adaptation strategy, and only one option could be the primary strategy. As a result, the options were independent. Alauddin and Sarker (2014) performed similarly identify the primary adaptation strategy of farmers in their study. In addition, we employed the well-known Hausman test to validate IIA's assumption. The assumption necessitates that the likelihood of a respondent adopting one adaptation strategy is independent to the possibility of adopting another. The parameters of the MNL model are usually not directly interpretable because the MNL model's parameter estimates only show the direction of the independent variables' effect on the dependent (response) variable; they do not indicate the actual magnitude of change or probability (Deressa et al. 2009). The marginal effects (MEs) that measure the impact on the probability of observing each of several outcomes are meaningful and interpretable in this case (Cameron and Trivedi 2009). Hence, marginal effects were estimated as well.

Results and discussion

Socioeconomic characteristics of the farmers

The sampled wheat farmers' major socioeconomic characteristics are presented in Table 1. It shows that most of the farmers (45.6%) in this study were over 50 years old, and the mean age of the sampled wheat-producing farmers was 49.13 years. It is noteworthy that older farmers have higher experience in observing the incidence and effects of climate change. More than one-third of wheat farmers were illiterate, which is higher than the national illiteracy (BBS 2020). However, their average year of schooling was estimated at 6.23 years. The mean size of the farmers' households was 4.93 members per family, which is slightly higher than the national average (ARSS 2019). The results also reveal that almost all the respondents were involved in agriculture, while 91.88% of them chose farming as their primary occupation, and 8.12% stated it as a secondary occupation. The average farm size of the farmers was 1.31 ha, while an average of 0.60 ha of land is devoted to wheat farming. The farmers' mean experience in farming was 23.18 years. The wheat farmers' households in the present study earn an average of BDT 156,625 annually.

Perception of climate change among the farmers

Perception about climatic variables

Farmers were asked about the changes they perceived on the specific climatic parameter. The responses of the wheat farmers were increased, decreased, or unchanged, and the results are depicted in Table 2. Responses were mutually exclusive. The results indicate that most of the farmers (76.25%) perceived that temperature had increased in their locality. About 77.50% of them perceived that yearly rainfall in their locality has decreased. Rahaman et al. (2016) found that the annual average rainfall in this region has declined from 151.50 to 138.09 mm during 1994–2013 period. Previous studies (Dendir and Simane 2021; Debela et al. 2015; Bewket and Alemu 2011) also reported respondents' perception of increasing temperature and decreasing rainfall. However, most of the farmers (59.38%) perceived that drought in their area has become more frequent. The meteorological study by Mondol et al. (2021) confirms the higher drought frequency in northern Bangladesh. Interestingly, nearly one-third of respondents think that the incidence of drought has decreased. This may be because of variability in land type or availability of groundwater. Availability of improved irrigation systems may also be the reason to observe less drought than those who do not have improved irrigation systems. Similar findings were reported by Ayanlade et al. (2018). The majority of the farmers (59.38%) believe that groundwater level has decreased over the last two decades. Shahid and Hazarika (2010) showed that the northwest region had a significant falling trend for annual maximum depths of ground water level and a persistent decline in the dry seasons. Groundwater levels are dropping in this area due to a lack of rainfall and over-exploitation of groundwater resources. Surface water such as ponds, rivers, and canals are also important sources of irrigation. However, about 70% of the farmers reported lesser water availability from these sources.

Heat waves are common phenomenon in northwest Bangladesh during summer. About 59.38% of the farmers in this study agreed that frequency had increased over the

Table 1 Socioeconomic characteristics of the farmers

Characteristics	Categories	% of respondents	Mean	SD
Age (years)	Young (up to 35)	14.4	49.13	11.04
	Middle (36 to 50)	40		
	Old (above 50)	45.6		
Education (years of schooling)	No schooling (0)	35	6.23	5.53
	Primary (1–5)	11.3		
	Secondary (6–10)	34.4		
	Higher secondary or above (> 10)	19.4		
Family size (no.)			4.93	1.68
Main occupation	Agriculture	91.88		
	Others	8.12		
Farm size (ha)			1.31	1.28
Farm size under wheat (ha)			0.60	0.79
Experience in farming (years)			23.18	11.44
Annual household income (BDT)			156,625	151,947

Table 2 Farmers' perception about climatic variables over the last 20 years

Climatic variables	Increased	Decreased	Remained the same
Average annual temperature	122 (76.25)	21 (13.13)	17 (10.63)
Average annual rainfall	29 (18.13)	124 (77.50)	7 (4.38)
Frequency of drought	95 (59.38)	50 (31.25)	15 (9.38)
Availability of groundwater	13 (8.13)	95 (59.38)	52 (32.50)
Availability of surface water	24 (15.00)	112 (70.00)	24 (15.00)
Frequency of heat wave	95 (59.38)	34 (21.25)	31 (19.38)
Duration of winter season	19 (11.88)	135 (84.38)	6 (3.75)
Frequency of cold wave/fogging	26 (16.25)	126 (78.75)	8 (5.00)

last two decades. The duration of the different seasons is very important in agriculture. Every crop has an optimum season in which its production is highest. Wheat is grown during winter in Bangladesh as its optimum temperature is available at this time of the year. The majority of the farmers (84.38%) observed the winter season to be shorter during the last two decades. Cold waves and fogging in the winter season are important factors for wheat production. Unsuitable foggy events may cause considerable damage to field crops like wheat (Singh and Singh, 2010). Results show that about 78.75% of wheat farmers perceived decreased cold waves and fogging.

Farmers' perceptions of climate change were supported by observed climatic data. In the case of the yearly mean temperature, the country has observed an upward trend from 1901 to 2016 (Fig. 2). However, average yearly rainfall data during the same time period revealed a decreasing trend, which is consistent with the majority of farmers' perceptions (Fig. 3). Besides, the study by Mojid et al. (2019) using the data of Bangladesh Water Development Board (BWDB) reveals significant falling trends of the annual minimum and maximum depths groundwater in northwest Bangladesh. Due to this, the extraction is higher than the recharge from the surface sources declining the surface water availability (Rahman et al. 2022).

Perception about consequences of climate change in farming

The climatic change could affect agriculture in several ways in the long run. However, the effect of climate on agriculture is related to variabilities in local climates rather than in global climatic patterns. Therefore, when assessing the impact of climate change in a local area, climate variability in that area must be considered. Farmers' perceptions of the consequences on their farming due to climate change are presented in Fig. 4. It reveals that about 73% of the sampled farmers think that the timing of the rain had changed due to climate change which affects farming to a large extent. More than half of them (55%) declared that they observed higher

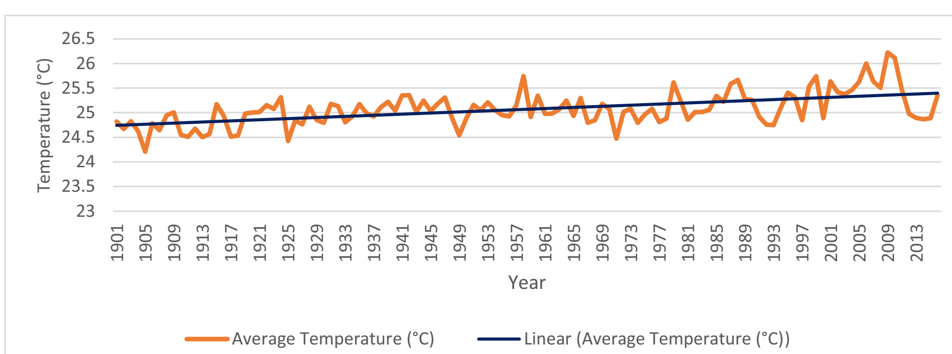


Fig. 2 Average annual temperature in Bangladesh from 1901 to 2016 (source: World Bank Data) https://climateknowledgeportal.worldbank.org/country/bangladesh/climate-datahistorical

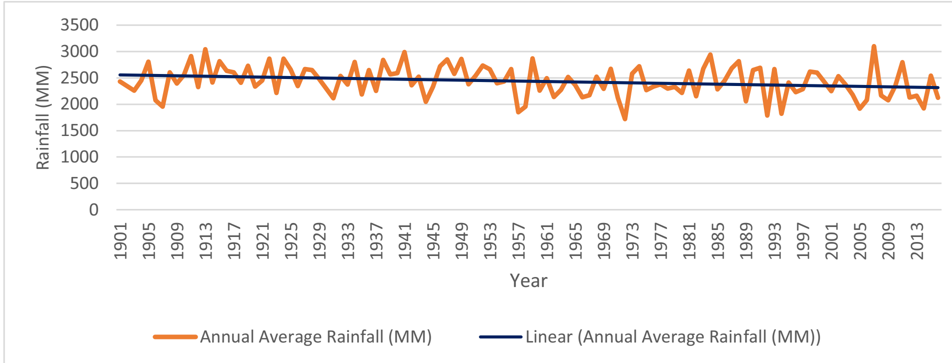


Fig. 3 Average annual rainfall in Bangladesh from 1901 to 2016 (source: World Bank Data) https://climateknowledgeportal.worldbank.org/country/bangladesh/climate-datahistorical

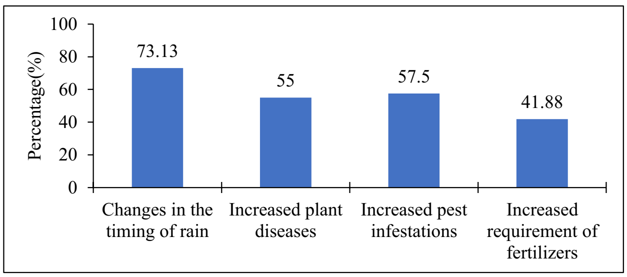


Fig. 4 Perception on consequences of climate change over the last 20 years (%)

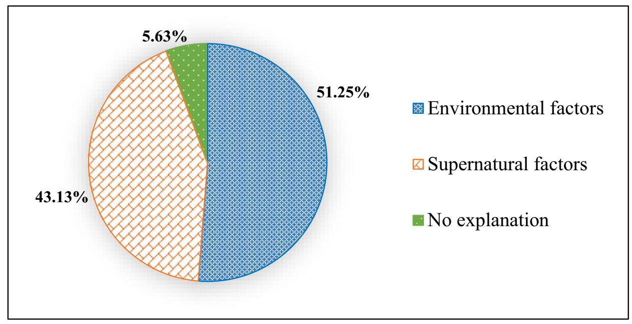


Fig. 5 Perception about the cause of climate change

diseases in their crops. About 57% of the respondents perceived increased pest infestations in their crops, and about 42% among the farmers perceived increased requirement of fertilizers. These findings are consistent with the studies by Mairura et al. (2021), Awazi et al. (2020), and Fahad et al. (2020).

Perception about the cause of climate change

Farmers' perceptions on the cause of climate change are influenced by their age, beliefs, education, experience, and availability of climate change information. They were asked whether environmental or supernatural factors cause climate change or whether there is no explanation. In this study, environmental causes of climate change implied the natural events such as greenhouse gases emission and ozone layer depletion induced by the human activities. This section assessed the farmers' understanding of the causality among the human actions and changing climatic indicators. Farmers' perception of the causes of climate change is presented in Fig. 5, revealing that more than half (about 51%) of the respondents perceived environmental factors as the cause of climate change. However, about 43% of the farmers perceived that climate change occurs due to supernatural factors. Previous studies also found similar findings in Zambia (Nyanga et al. 2011), Nigeria (Esan et al. 2017), and Benin (Zoundji et al. 2017).

Adaptation strategies of the wheat farmers

The adaptation strategies taken by farmers vary significantly according to region, land topography, the extent of extension services, and farmers' socioeconomic characteristics. This study found that wheat farmers in northwest Bangladesh tend to use nine different adaptation strategies. No adaptation is the base category in the study. It is worth mentioning that many farmers adopted multiple strategies over the years or in the same year. Figure 6 presented the percentage of wheat farmers in this study adopting different adaptation strategies to combat climate change.

The result revealed that the majority of the wheat farmers (57.5%) shifted to other rabi crops, which occupy the highest percentage of the farmers. Most farmers shifted to maize, potato, or other *rabi* crops after facing continuous loss in wheat due to decreased yield and low market price. In addition, other *rabi* crops such as maize, potato, and *boro* rice require less time to grow. Many farmers are growing two crops if they quit wheat. More irrigation for wheat was the second preferred adaptation strategy. The findings are interesting as northwest Bangladesh is a highly drought-prone and groundwater-depleted area. For that reason, the primary adaptation strategy is related to water scarcity. About 44% of the farmers change fertilizer and insecticide usage. About 19% of the farmers got involved in the off-farm business such as shopkeeping, day labor, and rickshaw-van

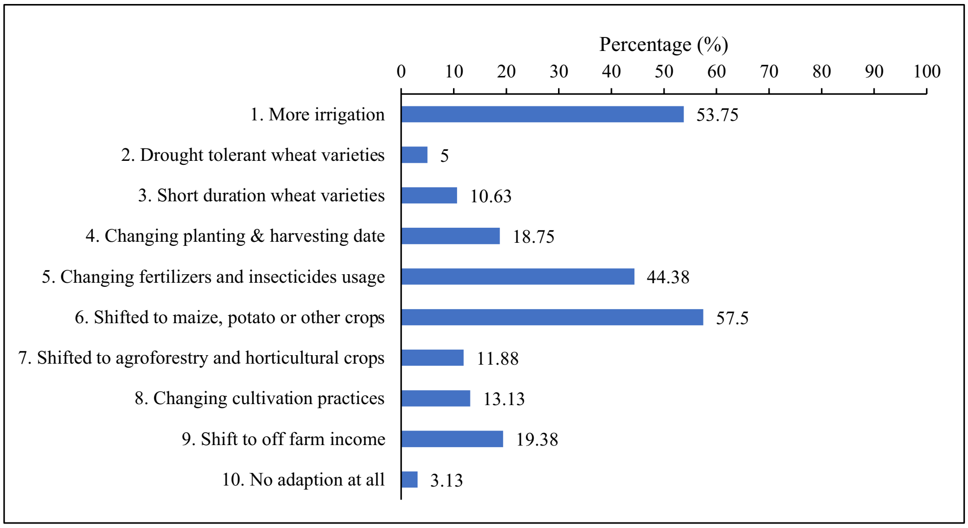


Fig. 6 Adaptation strategies of the wheat farmers

driver, besides continuing farming. About 19% of the farmers change planting and harvesting dates of wheat based on their personal experiences as well as advice of the extension officers or other farmers. Surprisingly, only about 11% and 5% of the farmers chose short-duration and drought-tolerant wheat varieties. The reason behind such results is that most of the farmers did not have much knowledge about the varieties they grow. They typically select varieties based on suggestions from extension officers or seed dealers. Sometimes, they buy the seed that is available in the markets. About 3% of the farmers were reluctant to adopt climate change–related adaptation strategies. They did not take any precautionary measures to mitigate the adverse effects of climate change on their farming. Several earlier studies have found that farmers adopt similar adaptation strategies to cope with climate change (Mairura et al. 2021; Dendir and Simane, 2021; Ogunleye et al. 2021; Antwi-Agyei et al. 2021).

In this study, the choices were not mutually exclusive. Therefore, the initial ten adaptation strategies were re-specified by grouping closely related options into six adaptation strategies following Alauddin and Sarker (2014) (Table 3). Then, we asked farmers to select a primary strategy among these six, and only one choice can be the primary strategy. Consequently, the choices were independent. In addition, to check the assumption of IIA, we employed the Hausman test. In the MNL model, the assumption of independence of irrelevant alternatives (IIA) has to be satisfied to ensure unbiased and consistent properties of the parameter estimates.

Table 3 illustrates the revised adaptation strategies which farmers chose as their primary strategy to mitigate the climate change effects. The results show that the majority of the farmers (38.75%) chose to grow non-wheat rabi and other horticultural crops as their primary adaptation strategy which is the combination of initial adaptation options 6 and 7. More irrigation for wheat was chosen by 16.25% of farmers and ranked the second preferred strategy by the wheat farmers. About 15% of farmers changed fertilizer and insecticide usage, and about 13.75% changed planting dates and other cultivation practices. Short-duration and drought-tolerant wheat varieties were the least adopted strategy as only about 6.88% of farmers chose this as their primary adaptation strategy. Initial adaptation option 9 (shifted to off-farm occupation) and option 10 (no adaptation) were

Table 3 Primary adaptation strategies by wheat farmers

Adaptation strategies	No. of respondents	Percentage (%)
More irrigation for wheat (option 1)	26	16.25
Short-duration and drought-tolerant wheat varieties (options 2 and 3)	11	6.88
Changing planting, harvesting dates, and other cultivation practices (options 4 and 8)	22	13.75
Changing fertilizer and insecticide usages (option 5)	24	15.00
Shift to non-wheat *rabi* and horticultural crops (options 6 and 7)	62	38.75
No adaptation (options 9 and 10)	15	9.38
Total	160	100

combined and assumed as the reference or base category in the multinomial logit model. Shifting to off-farm occupation is included in no adaptation because they actually did not adopt any strategy to continue wheat production.

Factors influencing the adaptation strategies

This section discusses the impact of various explanatory variables (education, family size, farming experience, total farm size, access to climate information, access to extension services, access to credit, access to subsidy, and access to electricity for irrigation) on the choice of adaptation strategies. However, the study did not find any significant impact of education and access to credit on adaptation decisions by the wheat farmers.

The impact of the above-mentioned explanatory variables on wheat farmers' adaptation choices was assessed through the multinomial logistic (MNL) regression model. Table 4 shows the findings of the MNL model.

The results from the MNL model show that the farmer's family size displayed disinclination (− 0.020) to adopt short-duration and drought-tolerant wheat varieties. Households with more family members are expected to divert from the agricultural sector to the non-farming sector in developing countries like Bangladesh (Al-Amin et al. 2019). Therefore, family size is negatively correlated with adaptation strategies. The study of Al-Amin et al. (2019) also found negative effect of household size on the adoption decision of climate change. Farming experience can influence farmers' choices of adaptation strategies. Maddison (2007) and Hassan and Nhemachena (2008) found that farming experience increases the likelihood of adopting climate change adaptation measures. In this study, more experienced farmers showed a slight (0.009) preference for additional wheat irrigation and short-duration and drought-tolerant wheat varieties (0.004). Farmers with more experience know when additional irrigation is required and are familiar with various wheat varieties, which aid them in deciding which varieties to grow. However, experienced farmers did not prefer to change fertilizer and insecticide (− 0.009) doses during wheat cultivation. The present study found that total farm size encouraged farmers to adopt short-duration and drought-tolerant wheat varieties (0.001). Farmers with large farms were likely to adopt this strategy. Because of their large farm size, they can take the risk of switching varieties. Fisher et al. (2015) also reported the positive association of farm size with the adoption drought-tolerant verities.

Results of this study reveal that farmers' access to prior climate information had a statistically significant negative impact on adopting more irrigation for wheat (− 0.177), changes in the planting dates and other cultivation practices (− 0.185), and non-wheat *rabi* and horticultural crops (− 0.420). Alauddin and Sarker (2014) reported similar findings for rice farmers. However, access to prior climate information encouraged farmers to adopt short-duration and drought-tolerant wheat varieties (0.866) which supports the findings of Deressa et al. (2009). Extension services can influence the farmers' choice of adaptation strategies. In this study, access to extension services had a positive marginal effect (0.194) for adopting non-wheat rabi and horticultural crops. That means access to extension services encouraged wheat farmers to adopt non-wheat *rabi* and horticultural crops. Farmers might have some extension services which encourage them to produce other crops because of higher revenue. Makate et al. (2019) found that extension influenced farmers to adopt drought-tolerant maize.

Agricultural subsidies benefit farmers by lowering their farming costs. Furthermore, agricultural subsidies encourage more people to become involved in farming, which leads to increased agricultural production. The findings of the study revealed that access to subsidies had a positive impact on adopting more irrigation for wheat (0.296), changing planting dates and other cultivation practices (0.210), and changing fertilizer and insecticide usages (0.125). Alauddin and Sarker (2014) reported negative effect of subsidy on adopting more irrigation for rice and positive effects on adoption of modern varieties and other crops. However, the study also revealed that access to subsidies had a negative impact on farmers adopting short-duration and drought-tolerant wheat varieties (− 0.849). The results show that electricity access discouraged farmers from providing more irrigation for wheat production (− 0.099). Since electric pumps are more efficient than diesel pumps, irrigated water is utilized more efficiently, and therefore, less water is needed for irrigating the farm. As a result, farmers having access to electricity were less inclined to increase wheat irrigation. Another factor could be the high cost of electricity. This study also revealed that access to electricity for irrigation encouraged wheat farmers to change fertilizer and insecticide usages (0.165).

Adaptation barriers faced by wheat farmers

Wheat farmers were confronting various adaptation barriers in the study areas. Figure 7 depicts the barriers that farmers were faced in implementing the adaptation strategies. The highest number of wheat farmers in this study identified the lack of information about anticipated climate change as a hindrance to their adaptation process (62.50%). Due to a lack of knowledge about potential climate change, wheat farmers were experiencing difficulties mitigating the effects of climate change on their production in the study areas. The fair price of wheat ensured stable income which increases their interest in employing necessary adaptation strategies to climate change. Results revealed that lack of fair price was one of the major barriers in taking adaptation strategies by the wheat

Table 4 Parameter estimate and marginal effects of multinomial logit model for factors influencing farmers' adaptation strategies

Explanatory variables	Dependent variables (adaptation strategies)									
	More irrigation for wheat		Short-duration and drought-tolerant wheat varieties		Changing planting dates and other cultivation practices		Changing fertilizer and insecticide usages		Non-wheat *rabi* and horticultural crops	
	Estimated parameter	Marginal effect	Estimated parameter	Marginal effect	Estimated parameter	Marginal effect	Estimated parameter	Marginal effect	Estimated parameter	Marginal effect
Education (years of schooling)	−0.007	0.001	0.022	0.002	−0.007	0.001	−0.087	−0.009	−0.018	0.002
Family size (no.)	−0.042	−0.015	−0.297	−0.020**	0.096	0.004	0.221	0.017	0.137	0.021
Farming experience (no. of years)	0.105***	0.009***	0.108**	0.004**	0.073*	0.004	−0.040	−0.009***	0.025	−0.004
farm size (decimal)	0.002**	0.001	0.003**	0.001**	0.002*	0.001	0.001	−0.001	0.001	−0.001
Access to climate information (1 = yes, 0 = no)	−0.297	−0.177**	15.913***	0.866***	−0.979**	−0.185***	−0.027	−0.042	−0.509	−0.420***
Access to extension services (1 = yes, 0 = no)	0.713	−0.058	0.729	−0.023	1.119	0.001	1.025	−0.016	1.673*	0.194**
Access to credit (1 = yes, 0 = no)	−0.199	−0.021	0.775	0.049	−0.019	0.011	−0.563	−0.059	−0.079	0.010
Access to subsidy (1 = yes, 0 = no)	0.599	0.296***	−16.167***	−0.849***	0.666	0.210***	0.027	0.125*	−0.843	0.131
Access to electricity for irrigation (1 = yes, 0 = no)	−0.258	−0.099*	0.790	0.021	−0.015	−0.057	1.819*	0.165**	0.623	0.022
Constant	−2.879**		−19.758***		−2.541		−0.902		−0.729	
Number of observations	160									
Wald $\chi^2(45)$	2278.97***									
Pseudo R^2	0.1490									
Log pseudolikelihood	−221.39014									

***, **, and * indicate the significance level at 1%, 5%, and 10%, respectively

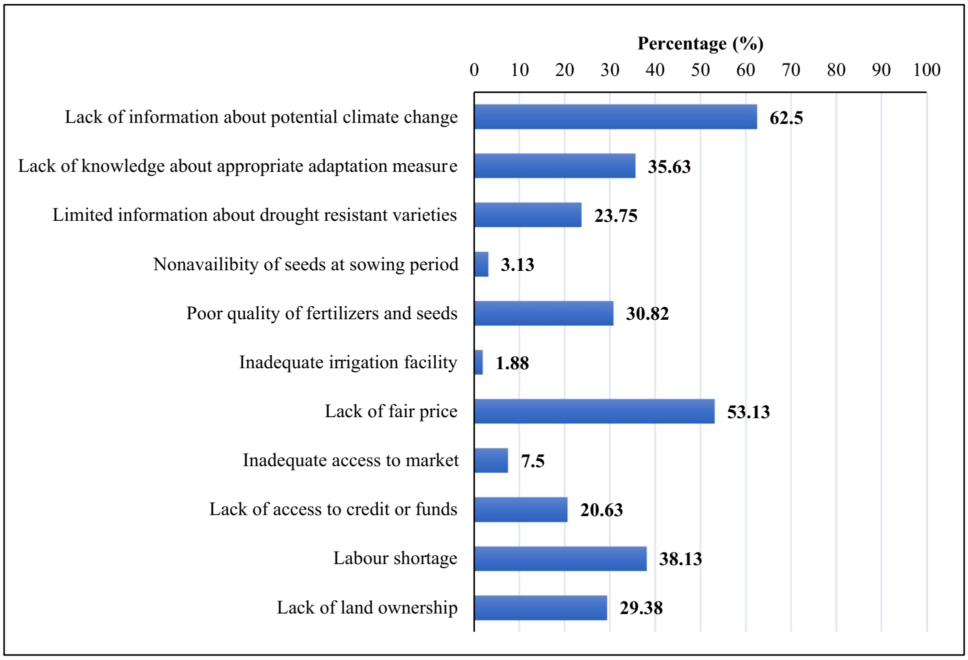


Fig. 7 Barriers faced by wheat farmers to take adaptation strategies

farmers in the study areas. It ranked 2nd among the identified problems (53.13%). In this study, about 38.13% of farmers reported labor shortage (ranked 3rd) as a major concern in their adaptation process. This study found that about 35.63% of wheat farmers lacked knowledge about appropriate adaptation measures in the study areas which ranked 4th among the identified problems. Therefore, it is necessary to make the farmers aware of various climate change events and educate them with appropriate adaptation practices. The present study found that about 30.82% of wheat farmers mentioned poor quality of fertilizers and seeds (ranked 5th) as a constraint in their production and adaptation to climate change. Lack of land ownership (ranked 6th) constraints about 29.38% of the wheat farmers to adopting any adaptation strategies to climate change. The results indicated that about 23.75% of farmers considered inadequate knowledge of drought-tolerant varieties (ranked 7th) as a major adaptation barrier to climate change. The inadequate credit facility is another major problem faced by the farmers in the study areas. About 20.63% of the farmers surveyed mentioned that they had limited access to credit (ranked 8th), which constrained them from effectively adapting to climate change. In this study, about 7.5% of wheat farmers considered the inadequate access to the market (ranked 9th) as a barrier to their adaptation process. About 3.13% of wheat farmers reported the lack of seed availability (ranked 10th) during the sowing period as a constraint in adapting to climate change. This delayed sowing, leaving them unable to cope with climate change if unfavorable climatic events occurred. This study found about 1.88% of the wheat farmers considered inadequate irrigation facilities (ranked 11th) as a barrier to their adaptation process.

Conclusions and policy recommendations

Bangladesh is one of the most vulnerable countries to climate change. Climate change is threatening the agriculture sector and the country's food security. Wheat is the second important staple after rice in Bangladesh. However, wheat production is being reduced as a consequence of climate change. To overcome this situation and for sustainable wheat production, farmers are adapting to the changing climate by employing various adaptation measures. Therefore, it is crucial to investigate the major adaptation strategies adopted by farmers and the key factors influencing their adaptation decisions and strategies. However, farmers' adaptation decision is influenced by their perceptions of climate change. Consequently, it is also important to study wheat farmers' perceptions regarding climate change. Therefore, the present study addressed these issues intending to provide valuable insight into how farmers cope with climate change in Bangladesh and add knowledge to the climate change literature. The findings will help farmers and policymakers to develop better climate change adaptation strategies, which will contribute to sustainable wheat production in Bangladesh. The results show that most of the farmers perceived more frequent drought due to higher temperature, decreased and irregular precipitation, reduced availability of ground and surface water, and shorter winter seasons over the last two decades. The study found that farmers in the study areas adopted various adaptation strategies, including more irrigation, switching to other crops, and changing fertilizer and insecticide usage to mitigate the adverse effect of climate change. The results revealed that the farming experience, access to climate change information, access to subsidy, family size, farm size, extension services, and availability of electricity for irrigation were significant determinants influencing farmers' adaptation decisions and strategies. The study identified that the farmers were facing various challenges while implementing above-mentioned adaption strategies. The findings indicated that along with low wheat prices, wheat farmers primarily faced information and knowledge-related barriers, as well as resource and infrastructural constraints to adopt the adaptation strategies. The information and knowledge-related barriers include inadequate information and knowledge of potential climate change, appropriate adaptation measures, and drought-tolerant wheat varieties; resource and infrastructural constraints were labor shortages, poor quality fertilizers and seeds, insufficient credit facilities, lack of land ownership, seed availability, market access, and inadequate irrigation facilities.

These insights suggest several policy recommendations for creating an enabling environment for adaptation to climate change in northwest Bangladesh. First, climate change–related information and knowledge should be disseminated to farmers. Government and private extension bodies can provide weather forecast and early warning information at the local level via instant messaging or phone call. Since most farmers now have mobile devices, timely transmission of weather-related information via mobile can help farmers adopt appropriate adaptation strategies and reduce crop loss due to the adverse impact of climate change. Second, proper extension services must be ensured to the farmers, including information accessibility, community education, and training on climate change adaptation strategies. Government and private extension authorities can give technical support to farmers to adopt appropriate adaptation technologies at farm level. They can also provide digital services via an online portal to help farmers gain knowledge and skills in order to employ climate-smart technologies. Third, since wheat is an important staple, initiatives should be taken to encourage farmers to continue wheat farming. This is because the findings revealed that the majority of farmers in the study areas chose to grow non-wheat rabi and other horticultural crops as their primary adaptation strategy to climate change. Farmers should provide quality seeds, fertilizers, adequate credit, and irrigation facilities, as these are some of the major climate change adaptations' barriers mentioned by the farmers. Fourth, the fair price of wheat should be ensured to farmers through improved market access and government intervention through market price monitoring. Finally, agricultural research must be strengthened to innovate climate-smart technologies and drought-tolerant wheat varieties, which will be resilient to adverse climates. More effort must be imposed to disseminate these innovations from the lab to the field. Effective implementation of these proposed policies may benefit wheat farmers and can greatly reduce the negative effects of climate change on wheat production in northwest Bangladesh.

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Data availability Data may be available from the corresponding author upon request.

Declarations

Ethics approval The authors of this manuscript have agreed to authorship, approved the manuscript, and given consent for submission and subsequent publication of the manuscript. The authors of this manuscript also assure that they follow the Springer publishing procedures and agree to publish it as any form of access article confirming to subscribe access standards and licensing.

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