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Posted Date: 7 November 2024

doi: 10.20944/preprints202411.0576.v1

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Wheat Declining in Bangladesh: Considering Factors and Possible Solutions to Increase Its Production

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Abstract: Wheat has to face the effects of global warming standing on the thread worldwide, and competing with many crops in the Rabi season (15 Oct to 15 Mar). Wheat is Bangladesh's second staple, meeting 13.6% of the country's cereal demand. However, despite an annual demand of 7.5 million metric tons (MMT), domestic wheat production in the 2023-24 season was only 1.19 MMT, covering just 15.9% of its demand and necessitating imports costing $2.21 billion. Demand continues to rise by 7-13% each year. Wheat production has declined from 1.99 in the 1998-99 season to 1.19 MMT in the 2023-24 season due to high crop competition with *Boro* rice, maize, mustard, and other crops during the Rabi season. Wheat production is reduced by other factors, such as low prices and insufficient mechanization, lack of time decision, etc. to purchase wheat grains by the government and businessmen which discourage framers from its cultivation. Expanding wheat cultivation with high-yielding stress-tolerant varieties in fallow lands and non-traditional areas would reduce greenhouse gas (GHG) emissions, malnutrition, groundwater harvesting, etc. Our study aims to offer new insights to policymakers and national and international benevolent agencies regarding the reasons behind the decline in wheat production and potential strategies to increase it. Additionally, this content will provide guidelines for policymakers and other stakeholders on how to reduce severe malnutrition and minimize greenhouse gas emissions and groundwater harvesting, thereby supporting the implementation of the United Nations' Sustainable Development Goals (SDGs).

Keywords: crop competition; global warming; greenhouse gas emission; groundwater scarcity; wheat deficit; wheat production

Introduction

Wheat is a vital staple food worldwide, but its production is hampered due to global warming, long-term unrainfall turning regions into drought, sometimes long-span cold, heat waves, etc. It is enriched in protein, vitamins, minerals, and proteins, and is economically significant. In Bangladesh, spring wheat was introduced in 1968. Historically, wheat was a common food in the country. The production peaked at 1.91 MMT in the 1998-99 season covering 0.88 million hectares of lands (Mha) and, then declined to 0.311 Mha of lands cultivated in 1.19 MMT in the 2023-24 season du e to low profitability, lack of mechanization, and huge competition with other crops. Farmers face challenges, such as high seed requirements (120-140 kg/ha) (Akhter et al. 2017) and limited seed availability in the market. In the 2022-23 season, 40-45 thousand MT of wheat seeds were needed, but government and private agencies supplied only about half of it. The remaining amount of seeds farmers preserved themselves. Moreover, importing wheat seeds is problematic as they often fail to adapt to local climatic conditions, hence only plants grow without grain-filled panicles. Further, wheat is eco-friendly, requiring fewer inputs like fertilizers, pesticides, and irrigation water (600-800 L kg^{-1}) for production than *Boro* rice (3000-5000 L/kg) (Tuong, 2008; Reddy et al. 2014). Further, no major insects infest to wheat crop. The government promotes sustainable groundwater use by encouraging low-water crops like wheat, maize, barley, foxtail millet, etc. Increasing wheat production can reduce reliance on imports, enhance food security, and support environmental sustainability. Global warming significantly impacts wheat cultivation in Bangladesh.

The annual demand for wheat grains was approximately 7.5 MMT, but production was only 1.19 MMT in the 2023-24 fiscal year (FY), meeting only 17.6% of the total requirement (BBS, 2023; BWMRI, 2023; DAE, 2023; MoA, 2023). Further, wheat demand in Bangladesh grows by 5-10% annually (BBS, 2023; USDA, 2023). In the 2022-23 FY, nearly 6.1 MMT of wheat grains were imported to meet the annual demand exchange of over 2.21 billion USD (BBS, 2023; FAO, 2023). Cereals are crucial food grains whose annual requirement in Bangladesh was 51.4 MMT in the 2022-23 FY (Jul-Jun), including wheat grains at 7.0 MMT (contributing 13.6% of the total cereal requirement) (BER, 2024). Food grains production was 48.9 MMT in 2022-23 FY, and in 2023/24 FY, cereal production has been fixed target of 49.5 MMT, and 8.6 MMT for imports, of which wheat was 6.1 MMT (almost 70.9% of the total cereals imports), 0.25 MMT for rice, and 2.1 MMT for maize (FAO, 2023; BER, 2024). Therefore, the country lies behind in wheat production, although it is almost self-sufficient in rice production. It was surprising for us that the country had to spend more than 2.21 billion USD on wheat grain imports in the 2022-23 FY, which was 2.17% of the total imports of the country (annual import of 92.5 billion USD) (BER, 2024) (USDA, 2023; BBS, 2023; BWMRI, 2023; DAE, 2023; MoA, 2023; FAO, 2023). Bangladesh will be the sixth largest wheat importer country by 2033/34 FY (targeting 6.9 MMT), while China, Nigeria, and the Philippines will stand the position of fourth-, fifth-, and seventh-largest wheat importer countries, increasing to 9.7, 7.0 and 6.9 MMT, respectively (USDA, 2023; FAO, 2023).

The IPCC (Intergovernmental Panel on Climate Change) predicts global temperatures could rise 1.5°C above preindustrial levels between 2030 and 2052, reaching 2°C by 2100 due to anthropogenic activities (IPCC, 2018). Bangladesh's average annual temperature is 25-35°C (BMD, 2022). From 1970 to 2022, Bangladesh showed an increase in average monthly minimum and maximum temperatures and relative humidity, while rainfall decreased (BMD, 2024). Projections indicate further temperature increases: 1.0°C by 2030, 1.4°C by 2050, and 2.4°C by 2100, with winter temperatures rising similarly (Sarker et al. 2012). From 1949 to 2013, annual temperatures increased by 0.13°C/decade, with seasonal and extreme temperatures rising faster (Zaman et al., 2013). Annual mean rainfall increased by 4.20 mm/year (Alam et al., 2023). Future projections warn of more hot days, heat waves, dry spells, and drought risks (Khatun et al., 2016). Wheat thrives best at 15-25°C temperature, but heat stress disrupts its growth and development, causing stunted plants and reduced yields (Alam et al., 2013a, Sun et al. 2022). The optimum sowing dates of wheat in Bangladesh are between Nov 15-30 for better growth and development (Alam et al. 2013c, 2014). Late sowing, especially after Dec 10, leads to poor grain quality due to high temperatures (Alam et al., 2013b, Hossain et al. 2021).

Wheat is a cool-loving herb whose growth and development optimum range is 15 to 25°C (Hossain et al. 2023). Heat waves or high temperatures are detrimental to morpho-physiological, biochemical, metabolic, and molecular processes (Alam et al. 2018a; 2018b; 2021). When wheat plants face heat stress, reactive oxygen species (ROS), and reactive oxygen species (RNS) are produced much more in organs than in the normal environment, which impairs metabolic processes and breaks down the bases of DNA, RNA, amino acids, fatty acids, and other macro- and micro-biomolecules (Alam et al. 2018a; Sun et al. 2022). Furthermore, photosynthates and metabolites can't move from source to sink; an increase in respiration and burning injury are found in plant organs, resulting in plant stunting. Plants also face leaf senescence early. As a result, unfilled, shriveled, shrinkage, and chappy grains are formed, ultimately reducing the grain yield havoc. BWMRI evidenced that wheat seeds sown between 15 to 30 Nov exhibit good growth and development; consequently, yields are achieved fair (Alam et al. 2014). Recently, because of the slow drainage of rainwater in southern regions, low land areas, and the lack of insincerity or unknown detrimental effects of late sowing, T. *Aman* rice harvested seeds throughout the entire Dec in the southern part of Bangladesh. After 10 Dec wheat seeding, the grain-filling period passes along with high temperature or heat wave (≥25°C), resulting in the generation of shriveled and chappy grains and impaired overall production (Hossain et al. 2021; 2023).

In the past two decades (2001-2020), wheat production has declined sharply compared with that in the previous decade (1991-2000) because of the increase in maize, potato, mustard, and *Boro* rice cultivation, i.e., crop competition, lack of mechanization in wheat production, processing, postharvest technology application, scarcity of seeds, insufficient support to cultivars, low price of wheat grains, high price of maize and potato, unwillingness of people feeding on wheat products, etc. To render wheat available to its consumers, protecting the environment from pollution from the overuse of pesticides, herbicides, fertilizers, and irrigation water for *Boro* rice, potato, tobacco, maize, T. *Aus*, etc., by refraining people from overeating rice, reducing nutrient deficiency in children and adults, minimizing diabetes risk, and checking foreign currency laundering abroad (2.21 USD/Year) might be increased wheat production by initiating fruitful programs. The budget allocations in research for developing technology (s) and biotic-abiotic stress-tolerant high-yielding variety (s) to mitigate the effects of global warming, an extension of newly released varieties, an increase in seed production, inputs support for wheat production to farmers freely, protection of soil health, training programs for the motivation of wheat cultivators, and their importance and nutrient values should be augmented. Therefore, our study investigated the reasons and factors underlying the decline of wheat production, challenges, and possible solutions to increase its production and delivered guidelines to the policymakers and national and international stakeholders.

Methodology

Data collection

Data on the annual area, production, and average yield of different crops for various years were collected from the Bangladesh Bureau of Statistics (BBS), Bangladesh Economic Review (BER), Department of Agricultural Extension (DAE), Ministry of Agriculture (MoA), Department of Agricultural Marketing (DAM), Food and Agriculture Organization (FAO) of the United Nations, United States Department of Agriculture (USDA), etc. Data on crop prices were collected from the BBS, DAM, USDA, and FAO. The yearly information on the number of pumps, tube wells, irrigated areas, and methods covered by various crops was obtained from the Bangladesh Power Development Board (BPDB), Bangladesh Agricultural Development Corporation (BADC), Barind Multipurpose Development Authority (BMDA), and BBS. Weather data were collected from the Bangladesh Metrological Department (BMD), Dhaka, Bangladesh. The seed distribution and production data included from the BADC, BMDA, MoA, and BER. Import information on various food grains was collected from the BBS, BER, FAO, and USDA. The money exchange rate BDT vs USD (BDT, Bangladeshi Taka; USD, United States Dollar) of different years was obtained from the Bangladesh Bank website. All the data were processed, compiled, and presented as figures and graphs with the help of Microsoft Excel 2019.

Results and Discussion

Factors affecting the decline of wheat production

High competition among crops during the wheat cultivation season

Wheat cultivation in Bangladesh faces high crop competition from other crops during the Rabi season. Cropping intensity was 214% in 2019 (Fig. S5A; BBS, 2019). Since 1990, farmers have favored

 doi:10.20944/preprints202411.0576.v1

Boro rice, potatoes, maize, and vegetables due to their higher prices and yields (potato: 22-25 t ha^{-1}, maize: 11-12 t ha^{-1}) compared to wheat (3.65 t ha^{-1} in 2023) (Fig. 1-2) (DAE, 2023). Rice, being a staple food with a high yield and easy processing, remains popular (USDA, 2023). Farmers prefer *Boro* rice and T. *Aus* after harvesting other crops like potatoes and mustard because they yield well at low input costs. Despite increased irrigation, wheat areas have stayed the me, though average yields have improved (Fig. 1).

In 1990-91, wheat's area, production, and yield were 0.60 Mha, 1.01 MMT, and 1.68 t ha^{-1}, respectively, compared to 0.32 Mha, 1.21 MMT, and 3.78 t ha^{-1} in 2022-23. Conversely, from that time, maize has grown significantly from 0.003 Mha, 0.003 MMT, and 0.98 t ha^{-1} to 5.63 Mha, 6.42 MMT, and 10.61 t ha^{-1}, respectively. The cultivation of potatoes, tobacco, mustard, vegetables, and other crops has also increased substantially over this period (Fig. 1-2).

Less profitable of wheat cultivation

Farmers in Bangladesh choose crops for cultivation which are economic profitability. Between 1980 and 2000, wheat cultivation peaked at 0.88 Mha (out of 8.3 Mha) and produced 1.91 MMT in 1998-99, with yields of 1.5-2.5 t ha^{-1} (Fig. S4; Fig. 1B). However, as the yield increased to 3.0-4.0 t ha^{-1}, the cultivation area declined due to lower profitability compared to *Boro* rice, potatoes, mustard, maize, etc. In 2022-23, wheat was priced at 45 BDT kg^{-1} (0.39 USD), but with an average yield of 3.65 t ha^{-1}, it was less profitable than paddy, which had a yield of 4.62 t ha^{-1} and was priced at 27.9 BDT kg^{-1} (fine grains) and 31.3 BDT kg^{-1} (coarse grains) (Fig. 1-3).

Potato and maize cultivation surged due to higher yields and prices, with potatoes yielding 22.90 t/ha at 21 BDT kg^{-1} (0.18 USD) and maize yielding 10.61 t/ha at 31 BDT kg^{-1} (0.28 USD). Thus, these crops are more profitable than wheat, mustard, and paddy, leading farmers to favor them (Fig. 3). Before 1990, limited irrigation facilities restricted crop choices to wheat, Aus, Aman rice, foxtail millet, barley, and jute. The lack of deep and shallow tube wells and limited electrical access further reduced wheat cultivation areas.

The revolution of Boro rice cultivation because of an unprecedented increase in irrigation facilities

Bangladesh has traditionally relied on rice-based cropping patterns. In the past, T. *Aman* (Jun-Dec) and B. *Aus* (Mar-Jun) were rain-dependent with low yields, leading to significant food deficits. The country's fertile plains, loamy soil, and accessible groundwater (up to 25 feet) made it suitable for agriculture, but poverty limited access to irrigation technology like shallow tube wells (STWs) and deep tube wells (DTWs), which were costly before 1990. Before 1971, 85% of the population lived in villages and depended on agriculture. Farmers used traditional methods to irrigate crops like wheat, barley, mustard, and vegetables. The three main cropping seasons are Rabi (16 Oct-15 Mar), Kharif-1 (16 Mar-30 Jun), and Kharif-2 (Jul-15 Oct), with the Rabi season featuring dry weather and low relative humidity. Initially, few STWs and DTWs provided irrigation, mainly to rich farmers through loans from the BADC (Fig. 4). After 1990, the government removed tariffs and taxes on irrigation equipment, reducing prices. STWs became affordable, leading to a significant increase in rice production and an agricultural revolution in the country. Farmers renting at least 50 decimals of land started purchasing STWs, leading to a significant increase in STWs, DTWs, and low lift pumps (LLPs) (Fig. 4). This allowed cultivation on previously barren charlands, reducing poverty and malnutrition as farmers grew crops like Boro rice, maize, jute, vegetables, tobacco, and more (Fig. 1-2, Fig. 4). Initially, wheat was favored due to low irrigation needs, but with improved irrigation, farmers shifted to *Boro* rice and other Rabi crops. By 1998-99, wheat cultivation peaked at 0.88 Mha and 1.94 MMT but then declined (Fig. 1) (Alam et al. 2013c). The cropping pattern changed to Fallow-*Boro* rice-T. *Aman* rice, with variations like Maize-Fallow-T. *Aman* and Mustard-*Boro* rice-T. *Aman* (Shahidullah et al. 2006; Nasim et al. 2018). Currently, wheat cultivation is less popular due to better irrigation for other crops, low price, and yield per hectare (Figs. 1, 2, 3, 4). Farmers now prefer patterns like Potato/Tobacco/Mustard - *Boro*/T. *Aus*/Jute-T. *Aman*. Wheat, sown in Nov, must be harvested by Apr, leaving insufficient time for other crops (Alam et al. 2014). Conversely, crops like potato and mustard allow for a subsequent *Boro* or T. *Aus* crop, maximizing yield with minimal expenses.

 doi:10.20944/preprints202411.0576.v1

Bangladesh's climate varies seasonally, with spring wheat grown from Nov to Mar in relatively cold temperatures (Hossain et al. 2023).

Temperature rise because of global warming affecting wheat production

Bangladesh, located between 20°34′N and 26°38′N latitude and 88°01′E and 92°41′E longitude, has a humid subtropical climate with distinct seasons: pre-monsoon (Mar-May), monsoon (Jun-Sep), post-monsoon (Oct-Nov), and winter (Dec-Feb) (Fig. S3). The country experiences warm temperatures, high humidity, and seasonal rainfall variations. Spring wheat, ideally sown from November 15 to 30, thrives between 15 to 25°C, yielding 3.0-3.65 t ha^{-1} on farms and up to 5.5 t ha^{-1} in research fields (BWMRI, 2023). Historical data from 1970 to 2022 shows temperature increases, with projections indicating further warming of 1.0°C by 2030, 1.4°C by 2050, and 2.4°C by 2100 (Fig. 5A-C, S1). Winter temperatures are expected to rise by 1.1°C by 2030, and the monsoon will warm by 0.8°C by 2030 (Agrawal et al. 2003; Ahmed, 2006). In recent years, temperatures have risen more significantly than in 1970, with increases in both minimum and maximum temperatures, though rainfall has decreased (Figs. 5, S1). The average relative humidity and rainfall patterns have also changed, affecting crop yields. The monsoon season remains crucial for high-yielding rice varieties like *Boro* rice, which are grown across the remaining 20% of the annual rainfall period (Jun-Sep) (Fig. S2). Wheat, a cool-loving crop, suffers under high temperatures, leading to stunted growth, early leaf senescence, and reduced yields. Proper sowing times from mid to late November are essential for optimal wheat production (Alam et al. 2014; Hossain et al. 2023).

Lack of varieties grown for combating heat, drought, salinity, and biotic stresses

Global temperatures are rising due to natural climatic changes and human activities, with projections indicating a 1.0°C increase by 2030, 1.4°C by 2050, and 2.4°C by 2100. Winter temperatures are expected to rise by 1.1°C by 2030 and 2.7°C by 2100, while monsoon temperature will increase by 0.8°C by 2030 and 1.9°C by 2100 (Fig. 5D-E) (Agrawal et al. 2003; Ahmed, 2006). Warming is anticipated to be more pronounced in winter than summer. This trend poses risks of more hot days, heat waves, dry spells, and droughts in Bangladesh (Fig. S3). Historical data shows an increase in annual temperatures and rainfall, with annual mean temperatures rising by 0.13°C per decade and mean annual rainfall increasing by 4.20 mm/year (Fig. S1, S2) (Alam et al., 2023). Coastal regions are particularly affected by salinity, with 1.06 Mha suffering from varying degrees of soil salinity, especially during the Rabi season (Fig. S3) (SRDI, 2010). Floods and cyclones exacerbate salinity issues, leaving land fallow during crucial growing periods (Fig. S6). To address these challenges, Bangladesh has developed salinity-tolerant rice and wheat varieties. The BWMRI released BARI Gom 25 in 2010, which tolerates up to 10 dS m^{-1} salinity (Monwar et al., 2023). However, more research is needed to develop heat- and drought-tolerant wheat varieties due to increasing temperatures and erratic rainfall. Additionally, climate change has led to new diseases and pests in wheat crops, including blast disease, *Bipolaris* leaf blight, and leaf rust (Islam et al. 2016; Singh et al. 2021). Ongoing research aims to create varieties resilient to these stresses (Hossain et al. 2021, 2023).

Wheat seeds unavailable in the markets

Wheat plants grown in a country with distinguished metrological and climatic attributes can't grow into new metrological and climatic conditions or adapt to new environments for 10 years. Wheat cultivation in Bangladesh faces unique challenges due to the need for locally adapted varieties. The development of wheat varieties that thrive under specific environmental conditions in the country requires significant investment in research and development, including screening, crossing, selection, verification, genetic engineering, and genomic selection at both the physiological and molecular levels. This process ensures that locally adapted released wheat varieties can withstand local pests, diseases, soil conditions, and climate aberrations. Given the specialized nature of wheat cultivation, it is understandable that seed companies in Bangladesh primarily focus on crops and vegetables that are more commonly grown or easier to cultivate in the country. Importing wheat

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seeds abroad must not be practical due to the necessity of having varieties tailored to local conditions. The challenge for farmers in Bangladesh, therefore, lies in accessing quality wheat seeds during the sowing period. If wheat seeds are not readily available in seed markets or through the BADC, the productivity and growth of the wheat sector could be hindered (Fig. 6-8). Addressing this issue may require collaborative efforts between agricultural personnel, research institutions, and Govt. bodies, and seed companies to ensure that farmers have access to the available seeds at the right time.

Insufficient extension of newly released wheat varieties to farmers

Since 2024, the BWMRI has released 38 high-yielding wheat varieties, some resistant to diseases and heat stress (BWMRI, 2024). To promote these varieties, BWMRI conducts around 2,000 demonstrations nationwide, offering free seeds, pesticides, and fertilizers. Each demonstration now covers 20 decimal plots, up from 10, and benefits 25 farmers per district, except in some areas with funding shortages. Demonstrations are crucial for popularizing new varieties, but older varieties suffer from decreased yield and quality over time. Adequate funding is essential to expand the use of these new varieties.

Recently, maize has been popularized among farmers as a high-economic crop

Maize, a C4 crop, thrives in diverse conditions, tolerates various stresses, and grows in poor or saline soils. Its adaptability and resilience make it less susceptible to pests compared to other crops. Maize's average yield per hectare is higher than most crops, except potatoes, and its profitability surpasses that of wheat, rice, and mustard. Maize is crucial for poultry, fish, and cattle feed, and its nutritional value exceeds that of rice and wheat. From 2000-01 to 2022-23, maize cultivation in Bangladesh increased significantly, with yield rising from 3.22 t/ha to 10.60 t/ha. In 2022, maize prices were lower than wheat, but its higher yield makes it more profitable. Maize's adaptability and low irrigation needs have driven its popularity and economic contribution.

Unfavorable weather during the wheat harvesting period

The optimum period of wheat seeding is from 15 to 30 Nov (Alam et al. 2013b; Monwar et al., 2023). Only research institutes and few farmers are inclined toward this production technology. Most farmers ignore it. Wheat sowing after 30 Nov results in a decrease in yield havoc, and 45-81g of grains per decimal declines for each day late sowing after 30 Nov (Alam et al., 2013a, 2013b). There are many reasons behind this. First, farmers are not aware of the wheat sowing date, and its detrimental effects. Second, wheat is sown after the late harvesting of T. *Aman* rice. Most in the regions, T. *Aman* rice is cut off in the 3rd to last week of Nov, even in Dec for the lowlands. Wheat sowed after 30 Nov is harvested in the 1st and 2nd weeks of Apr facing bad weather, such as pre-monsoon rainfall, storms, and forced wind flow (Fig. S3; Alam et al, 2013a, 2023b). As a result, the harvesting, threshing, cleaning, and processing of wheat are hampered. Furthermore, machines performing quickly these processes are not available to all farmers. Therefore, wheat cultivators face enormous misery, more money expenses, and ultimately production costs increase. Therefore, farmers are unwilling to cultivate wheat, but also *Boro* rice.

Rat havoc during the wheat ripening period

Rat attacks pose a significant challenge to wheat cultivation, especially when crops mature around late Mar to early Apr. Rats cut and carry nearly ripe wheat, causing substantial financial losses for farmers. Efforts to control rats are often avoided due to the time, labor, and cost involved. Wheat fields, often scattered among other Rabi crops, and dense wheat plants provide ideal conditions for rats. Traditional methods like flooding rat holes are considered outdated and labor-intensive. Currently, there are no effective chemical solutions for rat control, leading to ongoing losses in wheat production.

None program initiation for popularizing wheat-made food to the people

 doi:10.20944/preprints202411.0576.v1

Wheat-based foods are not widely popular in Bangladesh, despite historical consumption of items like chapati, bread, and wheat-roasted ground. The BWMRI, formerly known as the WRC, has developed 39 wheat varieties and associated production technologies since 1983 (BWMRI, 2024). However, the institute lacks a dedicated Division of Postharvest Technology and Nutrition, resulting in insufficient research and development on wheat-based food products and their dissemination. As a result, programs to promote wheat-based foods, advance processing technology, and provide nutrition training have not been implemented, hindering the popularity of wheat-based foods in the country.

Possible solutions to the increase in its production

Ensuring the price of produced wheat to farmers

The price is the main factor for farmers in cultivating wheat. Generally, farmers are interested in profitable crops. After harvesting the wheat, the Govt.'s target of wheat purchase should be fixed and timely just after wheat harvesting to avoid middlemen. It is noted that "the more ensuring the right price of wheat for farmers, the more increasing wheat production".

Ensuring seeds to farmers

A timely supply of well-germinated seeds to the market is the key way to increase wheat production. Since the imported exotic seeds of wheat do not directly grow in the country, emphasis should be given to seed production, and timely supply at the door of farmers. With the collaboration of Govt. and national and international partners, the BWMRI can take proper steps for seed production programs to be made available to the market. As a large volume of wheat seeds is required per hectare of land (120-140 kg/ha) (Akhter et al. 2017), wheat can be grown and stored for seeds by contact grower farmers, with the direct supervision of wheat researchers, agricultural extension workers, and other stakeholder personnel. Domestic private seed companies must be approached and motivated to produce wheat seeds.

Increased seed production by BADC

The BADC is the main seed production institute for all crops and vegetables in Bangladesh. Historically, BADC has produced more rice seeds than wheat seeds, with 1.47 MMT of rice seeds and 0.0133 MMT of wheat seeds in the 2022-23 season (Fig. 6-7). For that same year, the total demand for rice seeds was 0.344 MMT, of which 0.220 MMT (64%) was supplied by BADC, DAE, BMDA, and the private sector (Fig. 6-7). In contrast, the wheat seed demand was 0.0446 MMT, but only 0.0193 MMT (43%) was supplied (Fig. 6A). BADC has set targets for the 2022-23 to 2029-30 seasons to produce approximately 0.664-0.670 MMT of *Boro* rice seeds and 0.0199-0.0260 MMT of wheat seeds, which will meet 50-55% and 16-19% of the respective total demands. To address the shortfall in wheat seed supply, BADC should be prioritized for wheat seed production, and a robust marketing channel should be developed to ensure seeds reach farmers efficiently. Additionally, DAE, BMDA, the private sector, and other companies should be encouraged to increase their efforts in wheat seed production and distribution.

Initiating the programs for the development of research and technology and extension-related works for wheat

Massive programs should be considered to increase wheat production and popularize its products in the whole country. Bangladesh is the smallest country in the world and stands 90th in terms of area, oppositely occupying the 8th in terms of population (approximately 180 million people live there) (Worlodmeter, 2024). Wheat production technologies need to be extended to farmers. Farmers, extension workers, personnel of seed companies, and representatives of NGOs relating to wheat cultivation and seed production can be trained on wheat production technologies, seed production, processing, storing, etc.

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Application of Genetic Engineering and Molecular Biology to Develop Variety (s) Adaptations to Climate Change

Most farmers in Bangladesh typically sow wheat seeds in Dec due to the late harvest of T. *Aman* rice, despite research indicating a yield loss of 45-81 g/decimal for each day of delayed sowing after Nov 30 (Alam et al. 2014). Late sowing exposes wheat to high temperatures during the reproductive and grain-filling stages, resulting in poor grain quality and lower yields (Alam et al. 2013c). Southern regions, comprising 16 districts, suffer from salinity levels of 4.0-21.0 dS/m during the dry season due to seawater flooding, cyclones, and storms (Fig. S3). Droughts also occur in various parts of Bangladesh, particularly in the west and southwest, where groundwater is deeply buried. Wheat faces challenges from diseases such as leaf rust, wheat blast, and BpLB, as well as heatwaves, drought, salinity, and high soil acidity (Hossain et al., 2023). In the 2022-23 season, the average yield of spring wheat was 3.65 t ha^{-1}, lower than the yields of potato (22.9 t ha^{-1}) and *Boro* rice (4.10 t ha^{-1}) (Fig. 1-2). Advances in molecular biology, including stress physiology, genomic selection, recombinant DNA technology, and marker-assisted selection, offer promising approaches to developing high-yielding, stress-tolerant wheat varieties to address these challenges.

Extension of Wheat Cultivation in non-traditional Areas

BBS (2023) reported that Bangladesh has a total cultivable area of 14.76 Mha, but only 11.38 Mha are cultivable (Fig. 9). A staggering 6.71 Mha of land remains uncultivated (BBS, 2023). The non-traditional areas include charlands, haor areas (especially the Sylhet region), coastal areas (saline prone), and drought areas (especially in the southwestern region) (Figs. S3, S6). By meeting the rising demand for wheat, wheat can be extended in those areas. The prospects for wheat production in these areas are described in the following.

Extension of wheat cultivation in drought-prone areas (west- and south-western regions)

Bangladesh faces severe droughts almost annually, with major events occurring roughly every decade. In the past 50 years, around 20 significant droughts have affected over 39% of the land and half the population, particularly during the pre-monsoon and post-monsoon periods (Fig. S3). These droughts reduce streamflow, deplete groundwater, and impact crop production. The country has three cropping seasons: Kharif-1 (mid-Mar–Jun), Kharif-2 (Jul–mid-Oct), and Rabi (mid-Oct–mid-Mar). The Rabi season depends entirely on irrigation, while the other two are mostly rainfed. Droughts in the Rabi and Pre-Kharif seasons result from prolonged dry spells, high temperatures, and low soil moisture, with Kharif droughts affecting highland areas. The government's groundwater-saving policy encourages crop diversification to conserve water, promoting crops like wheat, potatoes, mustard, and pulses over water-intensive *Boro* rice. This policy has saved about 20% of irrigation water. According to the Agriculture Census (BBS, 2019), out of 6.76 Mha of net crop area (NCA), 5.09 million hectares are irrigated (Fig. 9; S5). Drought annually damages 2.32 Mha of T. *Aman* rice and 2.2 Mha of other crops. It also impacts orchards, forests, and the environment, affecting agricultural growth and food security. There is a 10% chance that 41-50% of the country will experience drought in any given year. The Barind Tract in the west and southwestern regions, including districts like Dinajpur, Rangpur, and Rajshahi, is particularly vulnerable to drought due to lower rainfall.

Extension of wheat cultivation in charlands

In Bangladesh, the Rabi season faces high crop competition with a cropping intensity of 214% (Fig. 9). Wheat demand increases by 7-13% each year Wheat cultivation could be expanded in charlands along rivers, covering 0.83 million hectares, with 0.52 to 0.79 million hectares suitable for cultivation due to the dynamic nature of these lands (Fig. S6). Charlands are home to nearly 10 million vulnerable inhabitants who rely heavily on agriculture. In the Sylhet division, significant fallow land indicates underutilized agricultural potential. Recent flash floods in 2022 damaged 0.798 MMT of paddy and seedbeds in haor areas, which are large floodplain depressions in the northeastern region

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covering approximately 1.99 Mha. The haor areas are crucial for local livelihoods but face challenges due to unique hydro-ecological features. The Master Plan for haor areas aims for comprehensive development by 2031-32, addressing flood management, crop production, and other critical areas. Extending wheat cultivation could be beneficial, as wheat is sown and harvested earlier than *Boro* rice, which is vulnerable to flooding during the harvest period.

Strengthening wheat cultivation in saline-prone areas mostly requires following during the Rabi season

The Bay of Bengal, located in southern Bangladesh, features the world's longest sea beaches (approximately 150 km). The region's sixteen coastal districts face significant salinity issues during the Rabi and Kharif-1 seasons, with 37% of coastal arable land affected (Fig. S5). Cyclones and storm surges frequently flood these areas with saline water, impacting crop cultivation, food security, and freshwater quality for over 20 million people (Fig. S3; S6). By 2081-2100, global temperatures are expected to rise by 1.5-2°C, causing significant sea level rise and increasing river and groundwater salinity in Bangladesh's coastal regions. This will affect about 2.9 million people by 2050 due to deficits in drinking and irrigation water. In the Barind area of northwestern Bangladesh, drought and rainfall variability create challenges for irrigation and agricultural productivity. The population here, primarily small and landless farmers, faces severe water shortages for irrigation and household use. The demand for wheat is expected to rise, but current wheat cultivation is limited due to saline water shortages. The rise in Boro rice production, driven by extensive groundwater use, has led to increased energy costs, declining water levels, and deteriorating groundwater quality. Nearly 80% of Bangladesh's groundwater is used for irrigation, with *Boro* rice cultivator consuming about 73% of it. This has resulted in significant financial and environmental challenges, including higher energy costs, reduced water levels, and deteriorating water quality.

Extension of the recently released varieties

The BWMRI still now released 38 high-yield wheat varieties (BWMRI, 2024). Of them, BRAI Gom 30, Of them BRAI Gom 32, Of them BRAI Gom 33, BWMRI Gom 1, BWMRI Gom 2, BWMRI Gom 3, BWMRI Gom 4, and BWMRI Gom 5 possess high-yielding, BpLB, leaf rust, heat tolerant attributes. These varieties can be extended to the farmers, and non-traditional areas, such as char lands, drought and saline-prone areas, and Sylhet regions in the country.

Means of the increase of wheat production supporting farmers

Every year, Bangladesh imports a huge amount of wheat grains, and its demand is at the rate of 7-13% (Fig. 10A). The country imports grains, (rice, wheat, durum, etc.) abroad, of them, 80% is wheat grains of the total imports (Fig. (10A-B). It is a great surprise that Bangladesh annually spends around 2.21 billion USD to import wheat grains (Fig. 10C) which is 86% of the total required since now nearly 7.5 MMT of wheat grains are required in the 2023-24 FY, but the domestic production was only 1.13 MMT same time. Wheat is an eco-friendly crop, which can be produced with less irrigation, fertilizer, pesticide, labor, etc. compared to *Boro* rice. The government should take a step giving subsidies to he farmers o produce wheat. If 25000, 38500, or 45000 BDT is given to the farmers as subsidies for wheat production, nearly 31.4, 19.8, or 17.0 MMT wheat grain will be produced, respectively (Fig. 10C). Thus way, the foreign currency spending can be reduced which will render a great contribute to the central reserve.

Recommendations and conclusions

Wheat grown during the Rabi season has to compete with many other crops, such as *Boro* rice, vegetables, maize, mustard, tobacco, etc. resulting in declining wheat cultivated lands and total production. There are many fallow lands scattered in the country as the drought, salinity, char lands, and non-traditional areas situated in the western, south-western, southern/coastal belt, and south-eastern regions, respectively, where wheat cultivation can be extended with biotic and abiotic stress tolerant high yielding varieties. Enormous groundwater pumping for *Boro* rice cultivation with the STWs, DTWs, LLPs, and electric mortar in the Rabi season used are responsible for the downward movement of the water table (3000-5000 liters or varied in research findings 1600-2000 liters (or 3300 liters water per kg wheat observed in another literature) of water are required for per kg of *Boro* rice production, rather wheat needs only 600-800 liters/kg. Consequently, drinking water poisoning caused by arsenic contamination can cause different health abnormalities for the people in the affected areas. Moreover, the burning of fossil fuels, which drive a large number of STWs, DTWs, and LLPs, and the generation of electricity for mortars are adding large amounts of GHGs (mainly CO_2, CO, CH_4, N_2O, NO, NO_2, etc.) causing air pollution to the atmosphere, accelerating global warming (Fig. 11). Notably, in Bangladesh, the 1°C temp was increased by 2022 compared to 1871 (Fig. 5). Further, the demand for wheat grains increases every year (at the rate of 7-13%) in the country, mainly for use in preparing feeds of livestock, poultry, and fish, the development of bakery industries, food habit diversification, havoc attacks of diabetes disease, etc. As a result, wheat grains have to be imported nearly 85% of the total domestic demand from the past decade (total consumption was 7.5 MMT, and domestic production was only 1.19 MMT in the 2023-24 season). Hence, nearly 2.21 billion USD had to be spent on wheat grain imports during the 2022-23 FY. Approximately 45600 BDT was paid for per metric ton of wheat grain imports during the period. If the Govt. subsidies to farmers, such as 25000 BDT, 38500 BDT or 45000 BDT per hectare of lands, 9.72, 5.36 or 4.59 Mha lands might be under wheat cultivation and produced 31.4, 19.8, or 17.0 MMT wheat grains, respectively, which will be surplus for Bangladesh (Fig. 10C). This information will provide new insights to the policymakers of Bangladesh, and national and international agencies on the reasons for the decline of wheat production, and possible ways to increase its production.

Authors' contributions: GF and MNA conceptualized the experiments. MNA and IS collected and compiled data. MNA analyzed data and drew all figures, labeled them, and described the methodologies. AR and AES supervised it. MNA wrote the original draft manuscript. GF, AR, AES, MMR, MMA, and IS revised, edited, and improved it. All authors accepted the final manuscript.

Funding source: This work was supported by the Ministry of Agriculture, The Government of the People's Republic of Bangladesh [Grant number 135015200, 2022), and denoted to Mohammad Nur Alam.

Declaration of competing interest: All authors have nothing to declare either financial or personal interest.

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