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Crop diversification, sustainable production, and consumption (SDG-12) in rural Bangladesh: insights from the northern region of the country

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Abstract

The present study aimed to understand the current situation of diverse crop production in the northern region of Bangladesh. It also focused on sustainable production and consumption (SDG-12) and its association with crop diversification in the study area. The study adopted several tools and techniques of qualitative methods to design, collect data, and analyze them. By utilizing a non-random, purposive sampling, we chose some selected areas in northern Bangladesh, and following the sampling procedure, 50 farmers (small-scale agriculture producers) were selected to answer the central research questions and study-specific objectives. As part of the qualitative data analysis technique, this research employed a 'thematic analysis' tool to categorize the collected data under appropriate sub-themes which highlighted the study's major aims and objectives. It is demonstrated that crop diversification is one of the most important strategies for ensuring sustainable agriculture and production. In addition, diverse agricultural production plays a vital role in ensuring farmers' accessibility to food for household consumption. The study recommends that crop diversification should be thoroughly encouraged by the government of Bangladesh (GoB) to achieve SDG-12 (Sustainable Production and Consumption) by 2030. Additionally, the relevant officials of the GoB should provide necessary high-yielding seeds of diverse crops among the peasants in rural Bangladesh. Further research can be carried out on climate-resilient local food production systems to ensure sustainable food production and consumption in the country.

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Introduction

With a rapid rise in population in Bangladesh, there has been a diversified growth in the use of land for things such as agricultural production, building and shelter construction. On one side, as the population expands, so does the need for food and other requirements[1–3]. A study by Akanda points out that fewer land is available for farming, which could cause a food shortage[4]. The government of Bangladesh (GoB) has implemented several projects, such as the Green Revolution in the early 1960s, to help fulfill the growing need for food, but even then, production could not keep up with the population's needs[1, 5, 6]. As a result, the relevant officials of the GoB are forced to import food from other countries. To mitigate the current shortages of food, diverse crop production could be one of the significant ways which help them ensure sustainable production and consumption[1, 5]. Bangladesh is a predominantly agriculture-based nation where more than 70% of people in rural areas are directly or indirectly involved in farming-related activities[7]. Rice dominates various subsectors of agriculture and accounts for roughly three-quarters of the gross crop area dedicated to rice production[7]. The continual practice of engaging in rice monoculture by farmers, however, creates several serious problems[8]: fewer workers in agriculture, depletion of soil quality, etc. Added to these issues, the country has been experiencing huge shortages in terms of producing diverse crops; for instance, wheat, onion, vegetable oils, and so on[8, 9], to name a few.

Crop diversification is deemed a cost-effective means of reducing uncertainties in farmer's income, especially among poor smallholder farmers in Bangladesh. Contrary to specialized farming, crop diversification is an effort to promote crop diversity by multiple cropping, intercropping, or crop rotation to enhance ecological systems' availability, sustainability, and productivity[10]. It might be a step toward more advantageous socioeconomic outcomes, minor crop value chains, and sustainable agricultural systems. Recent scholars Nyasimi et al. argued that farmers use biological cycles to reduce inputs, protect the resource base, increase yields, and decrease risk from ecological and environmental concerns[11]. Furthermore, it presents a significant chance to improve rural communities' ability to generate income and jobs[12]. Crop variety breaks the cycle of illness, inhibits the growth of weeds, and encourages the interaction of good soil microbes. Crop diversification increases crop productivity and land use effectiveness by enhancing the physical and chemical properties of soil[12]. Multi-crop production offers a lot of potential for addressing issues such as the comeback of weeds and pest insects, soil degradation, pollution of the environment, salinity of the soil, declining farm profits, and climate change. A study by Di Falco & Perrings argue that crop intensification systems with crop diversity improve a farm's net returns and overall system

productivity. Farmers are switching from low-value, low-producing crops to high-value, high-yielding crops to reap the rewards of crop diversification[13]. Thus, crop diversity plays an important role in accomplishing the objectives of dietary security, income growth, food security, employment creation, and the development of sustainable agriculture[2]. Agriculture diversification, in general, is the process of producing a variety of crops to meet the rising need for cereals, pulses, oilseeds, fibers, fuel, and feed by moving away from the geographical or temporal dominance of a single crop. It, moreover, demonstrates that the contribution of crop diversification to food security and nutrition, and the reduction of poor farmers' vulnerability to climate change has not been properly researched. Birthal et al. revealed that somewhat more than half of the gross crop area produces crops twice[14]. Except for a few cash and minor crops, the production of many crops, particularly cereal crops, has increased by almost three times during the past 40 years as a result of technical improvement.

Crop diversification is believed to be a widely prescribed means of agriculture and rural development[15–17]. Thus, it is considered an effective approach to utilize scarce land and valuable water resources, and it makes agriculture sustainable and environmentally-friendly[18–20]. It offers comparatively high returns from crops by minimizing price and yield risk created by climatic variability and price volatility of agricultural produce. Again, it offers higher labor productivity, optimizes the use of resources, and utilizes the land efficiently[21–23]. It also creates opportunities for more employment and higher income through higher efficient use of resources. As a result, it asserts that a thorough investigation needs to be conducted for the benefit of the nation's agriculture. According to the literature, there have been a lot of studies done on this topic in a variety of nations. However, Bangladesh has only seen a very small number of studies. According to the researcher's knowledge, this problem has not yet been the subject of a thorough empirical study. Studies conducted in Bangladesh have relied on survey and descriptive methods, which do not accurately depict the situation. In this context, the current study tries to examine the current situation of crop diversification in Bangladesh. New research and policy impact evaluation methods that follow a sustainability approach need to be undertaken to assess the contribution of crop diversification to SDG-12.

Several studies have been carried out on the relevant topic in different countries worldwide. However, a few studies have been carried out central to the specific studies in Bangladesh. After a careful review of relevant previous studies, we found this literature largely focuses on the climatic impact on crop production in Bangladesh and beyond. Few studies shed light on the current state of crop diversification, sustainable production, and consumption in rural Bangladesh. However, a few studies exploring the relationship between crop diversification and sustainable production and consumption have been carried out so far in rural Bangladesh. As a result, the present study aimed to examine the importance of diverse food production and its connection with SDG-12 in rural Bangladesh. Studies conducted in Bangladesh have relied on survey and descriptive methods, which do not accurately depict the situation. To fill the research gaps, the study sets the following research question: how does crop diversification lead to sustainable production and consumption in rural Bangladesh? To fully capture the central research question, the study has set the following research objectives: (i) to find out the current state of crop diversification in the study area; (ii) to uncover the role of diverse crop production for the protection against pests and disease; (iii) to explore the extent of safety against market oscillations by crop diversification; (iv) to assess the level of nutrition and food security among the people living in rural Bangladesh.

The conceptual framework: crop diversification, sustainable production and consumption

The study designed a conceptual framework by examining a range of relevant literature[7, 24–30] which guided us to explore the research question and specific objectives (Fig. 1).

The above framework reveals that the major three concepts such as crop diversification, sustainable production, and consumption are connected with the various interrelated factors. The various elements of crop diversification, starting from crop rotations, and mixed farming, to genetic diversification in the diversified fields, could play a vital role in ensuring sustainable production. Besides, diverse crop production leads to enhance soil fertility, improve productivity and yields, increase production, reduce the risk arising from seasonal factors, protect against pests and diseases, safety against market oscillations, reduce financial risk, and mitigate price risks. The diverse production is beneficial to food security, varieties of household diets, impacts on increasing food availability, and enhances varieties of nutrition for the masses.

Methods, materials, and procedures

Research design

This research employed a variety of qualitative methods and tools to gather and analyze data. These methods included using instruments such as interview guides and checklists to achieve the research objectives. Employing qualitative research techniques enabled us to thoroughly investigate and collect data, offering a comprehensive understanding of the perspectives and experiences of individuals regarding the topic in question. By utilizing an interview guide and checklist, the study examined the current status of crop diversification and its impacts on development, sustainable production, and consumption in the study area. Primary data have been gathered through Key Informant Interviews (KIIs) and Focus Group Discussions (FGDs), while relevant secondary data were obtained from existing relevant literature. To ensure that the in-depth interviews and FGDs were aligned with the research objectives, we prepared two sets of interview guides—one for in-depth interviews and another for FGDs—both containing open-ended questions. While creating these guides and checklists, we considered various factors, including conducting a field visit during the pre-testing phase, selecting indicators based on the conceptual framework, and conducting a systematic literature review on diverse production. With the intent of eliciting substantive responses from the participants, open-ended inquiries were employed to provide them with the opportunity to articulate their cognitive insights, subjective viewpoints, and experiential narratives without being limited to predefined response options. Subsequently, these responses were translated into the local language, Bangla, to ensure better comprehension and the active participation of the participants. We also

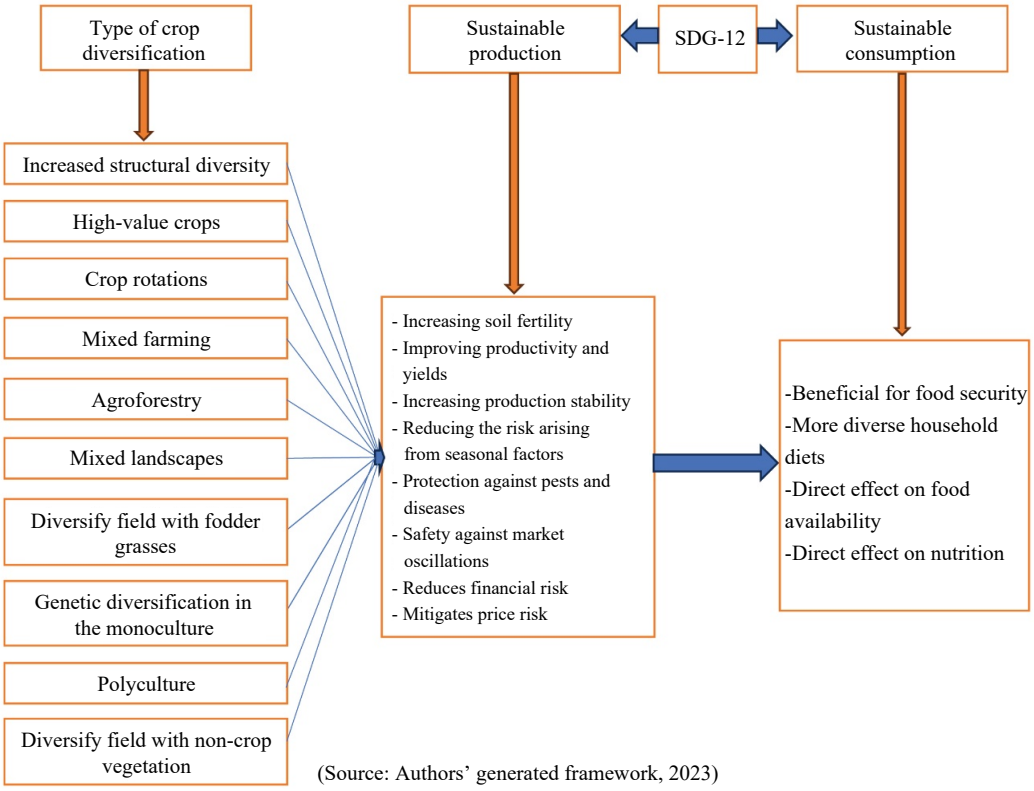

Fig. 1 Conceptual framework (crop diversification and SDG-12).

conducted a pre-testing of the open-ended interview guide to refine the process. During the in-depth interviews, we guided participants through the interview guide and checklist, which helped them address questions properly that had not been asked or answered, thereby encouraging detailed and extensive responses. All interviews were recorded and transcribed to preserve the collected data. Data collection took place between August 12, 2023, and September 26, 2023.

Selection of study area

The northern region is renowned for its significant agricultural food production, owing to its strategic geographic location and land utilization. Given the considerable abundance of food cultivation within this locale, the study has deliberately opted to focus its investigation on this particular area. In the process of selecting research participants, we purposefully chose four distinct zones within the district. This choice was primarily motivated by two key factors: firstly, these areas are home to a substantial population of small-scale food producers, i.e. farmers, numbering 28,921[7]. Secondly, this region stands out for its exceptionally high food production output compared to other regions within the district. Additionally, the chosen research site is conveniently located in close proximity to the researcher's place of residence.

In-depth interviews (IDIs)

For conducting in-depth interviews, the study chose a total of 50 key informant interviews (KIIs). We chose the informants based on the purposive sampling process who lived in the study region and had an in-depth knowledge about their food production and its association with the SDG-12. Before deciding on the interview schedule, we tried three interviewing procedures with informants who resided outside the research area to understand that they were understood and to determine whether any revisions or additions to the procedures were required. With the participants' complete permission, we recorded every interview using a tape recorder. To preserve the data, all of the interviews were taped, and afterwards, the transcriptions were accomplished. The information was gathered from 12 August 2023 to 22 September 2023.

Focus Group Discussions (FGD)

The research carried out five Focus Group Discussions (FGDs), involving a total of 40 participants from diverse socio-economic backgrounds. Before the FGDs were conducted, the research participants were engaged with to have the location and timing of these sessions arranged, customized to their preferences for participating in in-depth discussions. In an effort to ensure a consistent group for each FGD session, the study made certain that participants attending a particular session shared common characteristics. One of the co-researchers was responsible for documenting and audio-recording each FGD session. The initial FGD took place in the Mominpur region and involved eight participants, while the second was conducted in the Mohorkoia local area with seven attendees. The third FGD convened seven participants in the Khapara area, and the final FGD was executed in the Koilardor area with eight participants.

Data analysis techniques

Employing a qualitative approach for analyzing the extensive volume of gathered data presented a significant challenge. To address this, we conducted a meticulous data curation process, filtering out information that did not align closely with the study's objectives. The data filtration was guided by checklists developed based on the 'Crop Diversification and Sustainable Production and Consumption' framework. Initially, we

identified the key concepts relevant to the research objectives and compiled a list. Subsequently, we scrutinized the data for any incompleteness, inaccuracy, or irrelevance and removed such data. Then, a comprehensive review was conducted to ensure alignment with the central concepts. If any data was found to deviate from the primary concepts, efforts were made to reframe the information to bring it in line with these key ideas. The analysis of the collected data followed a thematic approach, wherein we identified prominent themes and patterns within the narratives emerging from the interviews. we highlighted both similarities and differences among the gathered data through this thematic analysis. In the subsequent step, the data was segmented, coded, and presented in accordance with the research objectives. The coding process was guided by the principles of interpretive and narrative analysis. The study provided a platform for informants to draw upon their knowledge, perspectives, and expertise derived from their personal experiences, thereby facilitating their sense-making, which holds central importance within this field of inquiry. By sharing the summary of the major findings with the research informants, we employed the 'member checking' technique which was used to confirm the validity and dependability of the collected data.

Data collection and management

This research primarily took into consideration the 'what aspect' of crop diversification. Later, the 'why' and 'how' aspects of crop diversification were examined according to the methodological framework. These three aspects, along with their dimensions of diversification, are closely linked. The collected data were thematically analyzed to understand the main themes and patterns extracted from the interviewees' narratives. The study demonstrated the comparison of both similarities and dissimilarities of the collected data through thematic analysis. Applying a manual strategy, we segmented the collected data by the processes of analyzing, structuring, organizing, and coding. Afterwards, collected data were segmented into subgroups and then narrowed down to specific themes.

Data sources

The main source of data comprised in-depth interviews with key informants at some selected study areas in the northern area of Bangladesh. An interview guide and a checklist were prepared to carry out the interviews. The informants were interviewed face-to-face at their preferred locations.

Reflexivity and positions

The interviewer gave details about the objectives of the research to the informants to ensure the collection of desired data. This arrangement helped establish trust between the interviewer and the informants, which proved crucial for data collection.

Ethical considerations

The interviewer tried to elicit oral consent from the informants and converse with them amiably to avoid any embarrassing or unpleasant situations. In addition, the questions were repeated and examples were added, whenever required for clarification.

Limitations of the study

The number of informants might not be enough to conclude and the FGD participants may not feel comfortable sharing their thoughts central to the research objectives. Apart from the qualitative research, the quantitative methods could provide better insights about the study research question, and the findings of the research could be more insightful.

Data analysis and findings

The following sub-themes have been developed to inspect the themes of the research objectives. Keeping in mind the whole excerpts from the informants, these sub-themes have also been created which reflected the aims and objectives of the research. Afterward, the segmented data, central to the study objectives, have been placed under the subthemes to make them relevant to the overall aims of the study (Table 1).

Diverse crops, and soil fertility

The study details the current state of diverse crop production and its connection with soil fertility, and other associated issues in the study area. Several informants point out that diverse crops are now cultivated in many agricultural fields. Focusing on the benefits of producing diverse crops in a year, many informants argue that 'if we grow three crops a year, we get three different agricultural products. Also, if we grow two crops at the same time on land, we can get more crops. Conversely, if we cultivate sugarcane only, then we merely get sugarcane for the whole year. When we cultivate three crops a year, the possibility of getting more crops increases'. Likewise, we can grow wheat first then jute then rice in the same agricultural land. This also helps to increase the soil's fertility. Some FGD participants state that we get more crops when we grow two crops a year. For example, if we grow corn with sugarcane, we can get corn alongside sugarcane. If we grow only sugarcane then we would not get corn. Informants argue that if we provide proper supplements when producing two or three crops on the land, we can ensure higher fertility of the particular land. For instance, one informant states 'I have two crops in my land; sugarcane and the other corn. Corn needs irrigation two or three times. Hence while irrigating corn, sugarcane will get more fertilization from the land. And it increases the land's strength'. Besides, the leaves of jute and the stems rot and turn into fertilizer which increases the strength of the land.

Multi crops, and protection from natural hazards

One informant argues that 'A natural hazard can only cause harm to one crop. Climatic hazards don't occur all year long'. In the case of the benefits of natural disasters, one FGD participant highlights that if we grow only one crop on land, then there is a higher possibility of destroying the crop by any hazard that may occur. 'If I cultivate sugarcane rice, wheat, and corn in a particular land, then a flood occurs, the rice and corn get flooded, but sugarcane can get value', added one informant. Thus, only the rice or wheat was destroyed in that piece

Table 1. Sub-themes of crop diversification and SDG-12.

	Sub-themes
i	Diverse crops, and soil fertility
ii	Multi crops, and protection from natural hazards
iii	Crop diversification, protection from insects
iv	Crop varieties, and financial benefits
v	Multi-crops household food availability, and people's accessibility to crops
vi	Food utilization, crop diversification
vii	Growing multiple crops, families' food security

Source: Authors' generated table, 2023.

of land. 'Conversely, if the land where I only used to cultivate one crop couldn't give me any other crop the whole year due to the natural disaster', replied another informant. 'Only one crop got destroyed in the land that had three crops, but I got two crops from that land. Last year jute was heavily damaged due to drought. Although jute was damaged, I managed to bring home two other crops (such as wheat and rice). Producing multiple crops reduces the risks created by natural disasters. Once my peas were ruined but my sugarcanes were good', was stated by many informants.

Crop diversification, protection from insects

One FGD participant states that we think growing more than one crop on a land reduces worm infestation and reduces crop diseases. The land where only one crop is cultivated in a year only gets properly irrigated once a year. The land is not irrigated again for the whole year. Due to that worms infecting the land, and crops staying in the land for one year, it carries many diseases. One informant echoed the thoughts and shared that for cultivating one crop on the land during the year, the worm infestation increases in that land and the crop is affected by disease. One of the FGD participants argued that they cultivate three crops in an agricultural land, which results in irrigation three times. They claimed that this method prevents worms from infesting the land. They explained that they first grow wheat, then rice, and before cultivating a new crop, they irrigate the land. To them, this process effectively eliminates any worms that may have infested the land during the cultivation of the first crop. Several informants argued that worm infestation could be extinguished, and crop diseases reduced by growing multiple crops. One informant said, 'Yes, the worm infestation decreases because producing crop after crop weakens the worm's ability to infest'.

Crop varieties, and financial benefits

Cultivating multiple crops on a single agricultural land has a positive impact on alleviating financial challenges. One participant in a focus group discussion highlighted three key ways in which this practice helps mitigate financial crises. Firstly, the participant mentioned that economic difficulties often arise from natural disasters. They shared an example from the past when they cultivated sugarcane in a plot of land that yielded only one crop per year. That particular year, their sugarcane crop was inundated due to flooding, leading to significant financial losses. However, the participants also cultivated rice on a separate piece of land where they had previously grown two other crops. When the rice crop was also affected by flooding, the financial impact was less severe because they had already harvested two other crops from the same land. Secondly, the participant discussed the challenges posed by pest infestations and diseases. They recalled a situation where their sugarcane crop suffered from a disease, resulting in substantial financial losses. This was exacerbated by the fact that sugarcane was a single-crop yield per year. The participant emphasized that if they had diversified their crops by cultivating three different varieties on the same land, the impact of the disease would have been less severe. While one of the crops might have been affected, they would still have had two others to rely on. The third reason highlighted was the fluctuation in crop prices. If a farmer grows only one type of crop on a piece of land and the market price. They explained that if they cultivated only one crop on a land and did not receive a favorable market price, they would face financial losses. In contrast, by growing three different crops on the same land, they could secure proper selling prices for two of them, reducing the risk of financial difficulties.

Another informant argues that growing three different crops on a single agricultural plot increases overall production. For instance, planting both corn and sugarcane on the same land results in additional sugarcane, reducing financial risks. Similarly, one participant shared a personal experience, noting that while their potato peas were ruined, their sugarcane was unaffected. This crop combination not only safeguards against losses but also stabilizes market prices, making products more affordable. They cited an example from the previous year when low wheat production led to increased wheat prices in the market (Table 2).

Multi-crops household food availability, and people's accessibility to crops

Several informants argue that producing diverse products help to keep the price stable and affordable to the masses. One FGD participant pointed out that 'if we, the farmers, grow three different crops a year, we can provide all kinds of products to the market. Due to that, the price of products will stay stable and within the affordability of the masses'. But in reality, this does not happen. In this connection, one informant argues that 'because a syndicate creates a false crisis with the use of the black market, many products go out of people's ability to purchase'. As a result, if the government properly monitors the market, the price will be stable and within people's ability to buy.

One of the Key Informants stated that 'it is usual that if I cultivate more than one crop, I can bring different food items for my family'. I cultivate multiple crops on most of my lands. Among these crops, there are rice, mustard, wheat, and lentils. I cultivate rice so that my family has access to rice for the whole year. Along with that, I cultivate wheat for flour and mustard for mustard oil. While asking the question: Do you think growing multiple crops keeps the products' market price stable and the prices are more affordable for the masses?, several KIIs argue that 'yes, I agree with it. Like, a few years ago the majority of farmers were growing lentils thus the price of lentils was stable'.

Table 2. Crop-diversification and sustainable production.

i	Diverse crops, and soil fertility
	(a) Possibility of getting more crops increases
	(b) Proper supplements when producing two or three crops
ii	Multi crops, and protection from natural hazards
	(a) Producing multiple crops reduces the risks posed by natural disasters
	(b) Less damages to be occurred by any hazardous event
iii	Crop diversification and protection from insects
	(a) Proper irrigation method prevents worms from infesting the land
	(b) Crop diseases reduced by growing multiple crops
iv	Crop varieties, and financial benefits
	(a) Multiple crops have a positive impact on reducing financial hardships
	(b) Multi crops reduce the fluctuation in crop prices
	(c) Diverse crops help to stable the market stability

Source: Authors' generated table, 2023.

Food utilization and crop diversification

Many FGD participants reveal that different foods consist of different nutrients. 'If I cultivate one crop in a year, I will get only one kind of food from that crop. If I cultivate two or three kinds of crops that can provide two or three different kinds of food for my family. We get different nutrients from different foods. I cultivate two to three crops on most of my land so that my family gets all kinds of nutrients. Among these crops, there are rice, wheat, mustard, lentils, sesame, corn, etc'.

One FGD participant said that 'it increases the family's food availability and security. If I grow one crop in my land, my family will only get one food the whole year. A family can't survive on one food alone'. Furthermore, another informant mentioned that if one food crop were to be destroyed, their family's food security would be jeopardized. They emphasize, 'When I cultivate two to three different types of crops, my family can rely on two to three different types of food'. Multiple informants argue that even if one of the three crops were to be destroyed, food security wouldn't be a concern. They explained that this practice of growing two to three crops on a single piece of land annually increases food availability and ensures food security for the entire year.

Many informants emphasized that when multiple crops are grown on the same land and provided with proper nutrients, increased fertility can be ensured. In this context, several informants argued that, for example, 'If I have both corn and sugarcane on a single piece of land, corn requires irrigation two to three times and the application of pesticides. The fertility that corn receives as a result of irrigation and pesticide use will also benefit the sugarcane, leading to higher fertility for that crop'. Several participants in the focus group discussions underlined that growing multiple crops diversifies the dietary habits of families, resulting in a variety of crops available for consumption. They explained that this diversity is achievable because of the production of various crops. 'Yes, it increases a family's nutrient intake. By cultivating different crops, we introduce a variety of foods into the household. Each food type contains distinct nutrients, thus allowing every family member to meet their nutritional requirements', many informants added.

Growing multiple crops, families' food security

Cultivating a variety of crops on a single piece of land enhances food security for families. Even if one crop is damaged, they can rely on others they have grown. An informant explained, 'By growing wheat after jute and rice after another crop, I've been able to produce more than with a single crop'. Multiple informants emphasized that growing diverse crops increases food availability and security for families. They annually produce rice grains for consumption throughout the year and keep lentils and wheat, selling the surplus. Many participants in the focus group discussions argued that cultivating multiple crops each year reduces financial risks. One interviewee stated, 'Harvesting multiple crops at different times keeps me financially secure'. Moreover, diversifying the crops also adds variety to families' food habits, as pointed out by one participant. Many participants mentioned that it broadens their diet, allowing them to store and consume different crops such as wheat, lentils, and potatoes. Regarding the question of whether growing multiple crops increases a family's nutrient intake, many informants highlighted that it indeed enhances food nutrients. 'For instance, I grow wheat, rice, lentils, mustard, and sugarcane, which provide various nutrients', one informant added (Table 3).

Discussion

The findings of the study point out that the agriculture sector has been facing a number of challenges such as reduction of soil fertility, pests and disease outbreaks in the crop fields, and decline in water levels, etc. It also shows that growing diversified crops on a land shortens the worm infestation and cuts down crop diseases. Crop diversification is considered a strategy for reducing problems, such as the reduction of pests and disease outbreaks in crop fields. It is also considered an effective approach to utilizing scarce land and valuable water resources, and it makes agriculture sustainable and environmentally-friendly[18, 19]. Studies by Husain et al. and Rahman showed that similar problems further create equal challenges cyclically[31, 32]. In addition, rice monoculture also reduces the production of non-rice crops, erodes biodiversity, and creates a nutritional imbalance. Crop diversification is considered a strategy for reducing the reported problems. It is also considered an effective approach to utilizing scarce land and valuable water resources, and it makes agriculture sustainable and environment-friendly[17–19].

The study pinpoints that diversifying crop production facilitates families to be less affected by changes in climate or price decreases, by which families build various livelihoods, applying different combinations of resources and assets. This research reveals that crop diversification has the potential to enhance resilience in agricultural systems against extreme climatic events. Kumari et al. and Barrett et al. revealed that if there is little diversification, the cultivation of low-profitability traditional goods will increase and the farming frontier will expand, driving deforestation and soil erosion[19, 33]. Therefore, Di Falco & Perrings argue that investing in agricultural diversification can stop environmental degradation by enabling multiple economically viable and more productive products[13].

This research shows that multi-production helps to enhance the overall production of the area and people's access to food increases significantly. It also highlights that peoples' capacity to maintain nutrient cycling and food production increases due to crop diversification. Lores[34] revealed that diversifying agricultural production has become a necessity, precisely because monocropping is predominant. Additionally, Kasperski & Holland explained that the main and most important reason to promote productive diversification is to generate economic

Table 3. Multi-crop production and sustainable consumption.

i	Diverse crops, household food availability, and people's accessibility to food
	(a) The prices of products remain stable within the affordability of the masses
	(b) Food security could be ensured due to multi production
ii	Food utilization and crop diversification
	(a) Different nutrients from diverse foods
	(b) Growing multiple crops diversifies the dietary habits of families, resulting in a variety of crops available for consumption
iii	Growing multiple crops, and families' food security
	(a) Food optimization could be greatly ensured
	(b) Growing diverse crops increases food accessibility vital for food security

Source: Authors' generated table, 2023.

growth[35]. Napoli & Velasco argued that diversification has a positive impact on farmers' incomes, lesser environmental impact, occupation of surplus family labor, and greater technical training to manage production[36]. The study also pinpoints that at the end of the day, diversification meets people's needs to improve their living conditions.

More than one crop on a single agricultural land minimizes the financial risk. The study, moreover, finds that total production increases in the case of producing three different crops on a single agricultural land. This result was also supported by Makate et al. in their studies[10]. They pinpointed that the growing rate of adoption improves crop productivity, income, food security, and nutrition at the household level. Overall, the results are indicative of the importance of crop diversification as a viable climate-smart agriculture practice that significantly enhances crop productivity and consequently resilience in rural smallholder farming systems. Diversifying agricultural production has become a necessity, precisely because monocropping is predominant. Kasperski & Holland and Rahman et al. showed that promoting productive diversification, the main and most important reason is to generate growth[35, 37]. This research argued that diversification has an impact on farmers' incomes, lesser environmental impact, occupation of surplus family labor, and greater technical training to manage production. Diversified productive activity yields a series of benefits; the most unquestionable is diversifying risk, by lessening exposure to potential price increases, demand changes, and quickly shifting technology[13, 35, 38].

The study finds that slightly more than half of the gross crop area grows crops twice in a cropping year. Yield and production of different crops, especially cereal crops, except for a few cash and minor crops, have increased by almost three-fold in the last four decades due to technological advancement. Crop diversification is considered one of the most ecologically feasible, cost-effective, and easier ways of reducing the effect of uncertainties, especially among small-scale farmers[3,14,24,39]. One common definition of crop diversification is the addition of more crops to an existing cropping system[40]. Clements et al. associate crop diversification with the replacement of low-value commodities by high-value commodities, usually fruits and vegetables for the export market[41]. Gunasena believed that crop diversification is a very important instrument for food and nutrition security, income growth, poverty alleviation, and employment generation. It also helps to use the land, water, and other resources judiciously[42,43]. Malik & Singh studied the extent of crop diversification[44]. They concluded that the availability of the market, increased demand for crops, export facilities, and proximity to town areas facilitate crop diversity whereas the absence of a proper market, price variability, and irrigation facility are the notable hindrances to crop diversification.

Our results also indicate that an increase in the rate of adoption improves crop productivity, income, food security, and nutrition at the household level. Johnson mentioned that Adam Smith perceived 'a significant relationship between the improvement of agricultural productivity and the wealth of nations'[45]. He quotes that, 'to improve and cultivate the land, one family's work can feed two families, so work by half of society is sufficient to provide food for all'[46].

Contributions to the research

The findings of this study will assist farmers, who own very small areas of land, to devise effective strategies for cultivating a variety of crops within a singular land parcel, thereby promoting the availability of sustainable and nutritious food options for consumers. The research outcomes are poised to furnish the necessary knowledge and expertise essential for cultivating diverse crops on an individual piece of land, playing a pivotal role in fostering sustainable agricultural practices and ensuring the nutritional well-being of the broader population.

The primary objective of this study is to impart valuable insights to both government and non-government officials, offering comprehensive guidelines for the widespread adoption of multi-crop production across the country. Farmers would benefit from learning necessary lessons that will help to enhance their income by focusing on high-value crops, while concurrently contributing to the maintenance of a sustainable soil structure over the long term. The diversification of cropping systems has the potential to increase cropping system intensity and boost food security. However, it is imperative to meticulously assess the synergies and trade-offs among various sustainability indicators, including nutrients, energy, and labor, in real-world on-farm conditions. In light of these findings, relevant stakeholders are encouraged to take proactive measures to overcome obstacles, ensuring the successful formulation and implementation of pivotal strategies aimed at promoting sustainable agricultural practices.

Conclusions and scope for future research

The study aimed to explore agricultural sustainability, and sustainable production with a focus on diverse crop production in some selected areas of northern Bangladesh. This research argued that agricultural diversity plays a vital role in ensuring agricultural sustainability in terms of production and consumption. Small scale farmers shared their insights on the essence of diverse food production, which significantly impacts enhancing land fertility, protecting crops from natural hazards, increasing peoples' access to daily essential foods, and so on. This research offers an in-depth investigation of the sustainability of agricultural systems applying a 'Sustainable production and crop diversification framework' that incorporates diverse crops, production, and consumption. The study pays special attention to the effects on people's food security, food utilization, protection of food insects, and their growing reliance on agricultural diversity and sustainability. Applying the conceptual framework, the research examined the diversity of cropping land use, an output decomposition method, and it evaluates changes in the diversity and sustainability of Bangladeshi agriculture as an exemplary case. Despite the fact that rice farming predominates and there is relatively little variety in the crops grown, the practices of crop diversification are increasing and working as a safeguard against a decline in agricultural sustainability. The demand for sustainable food product production is being driven by the increased knowledge that dietary choices have an impact on food production and their societal impact.

The scope and measurement of the concept of agricultural diversity are briefly discussed in this article, followed by a consideration of the effects on agricultural diversity and the

sustainability of agriculture's growing reliance on diverse food production. To address issues of agricultural diversity and sustainability, crop diversification, sustainable production, and consumption have been introduced and investigated. A relevant context for analyzing changes in the diversity and sustainability of agricultural practices and some selected areas have been explored. The study showed that a variety of strategies are used in sustainable farming techniques. Crop diversification is the most crucial strategy for the development of sustainable agriculture. It enables farmers to use biological cycles to reduce inputs, protect the resource base, increase yields, and decrease risk from ecological and environmental concerns. It presents a significant chance to improve rural communities' ability to generate income and jobs. Crop variety breaks the cycle of illness, inhibits the growth of weeds, and encourages the interaction of good soil microbes. Crop diversification increases crop productivity and land use effectiveness by enhancing the physical and chemical properties of soil. Crop diversification offers a large potential for addressing issues such as the comeback of weeds and pest insects, soil degradation, pollution of the environment, salinity of the soil, declining farm profits, and climate change. Thus, crop diversity has a good chance of accomplishing the objectives of dietary security, income growth, food security, employment creation, and the development of sustainable agriculture. The outcomes of this study will potentially facilitate the direction of academics and researchers - vital for effective implementations in the associated areas. The study results also help the farmers to produce more diverse crops in their agricultural fields which are crucial for meeting the current food crisis in the country. In addition, sustainable production and consumption will be largely ensured in the study area. The limitations of the research are twofold: the selection of the study area, since it does not represent the entire areas of the country; thus, the findings do not represent the entire picture of the said topics in the country. Secondly, the number of chosen informants does not necessarily represent the views of others who have not partaken in this study. As a result, the findings might not be representative in addressing the research questions.

Future studies should highlight climatic factors in producing diverse food production, and their association with sustainable food production and consumption in rural Bangladesh. Studies might focus on the facilities to be provided among the farmers so that they could be encouraged to produce diverse crops. The duties and activities of the relevant officials of the Government of Bangladesh (GoB) should also be given priority to assess how they support existing policies and strategies in reducing challenges to maintain sustainable agricultural development. Regarding the methodological issues, the quantitative research could provide important insights for thoroughly understanding the multi-production system and its relationship with people's sustainable food accessibility in the country.

Recommendations

The study recommends a few relevant strategies that need to be taken into consideration for enhancing the scope of diverse agricultural production in rural Bangladesh:

(i) The farmers could be inspired by being provided with a range of high-yielding seeds, and necessary financial and technical support to produce the diverse food production;

(ii) The local government could arrange regular meetings with the local farmers to make them understand the essence of diverse crop production and its connection with sustainable production and consumption;

(iii) The general population should buy the necessary daily crops that are to be produced in their local areas to promote the cultivation of multi-crops;

(iv) The GoB might need to create local and international markets to sell their multiproducts at more profitable prices;

(v) To exploit the potential of crop diversification, the Bangladesh government should come forward with developed market structures, road conditions, and making the irrigation system accessible for non-rice crops.

Author contributions

The authors confirm their contribution to the paper as follows: study conception and design: Rahman MM, data collection: Islam A; analysis and interpretation of results: Rahman, MM, Islam A, Ferdousee S; draft manuscript preparation: Rahman MM, Islam A. All authors reviewed the results and approved the final version of the manuscript.

Data availability

The data are not publicly available due to maintaining the confidentiality of the information provided by the informants.

Conflict of interest

The authors declare that they have no conflict of interest.

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