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Article

Adoption and profitability of BARI released garlic varieties in Bangladesh: a farm level study

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Abstract: Garlic, a vital spice crop in Bangladesh, holds a prominent position as the leading producer among all spice crops. This study was conducted in three garlic growing districts, namely Rajbari, Natore, and Dinajpur, with the primary objective of assessing the adoption status of BARI garlic varieties, analyzing their farm-level profitability, and identifying constraints faced by the farmers. A total of 300 farmers, with 100 selected randomly from each district, participated in this research. Data collection was carried out using a pre-tested interview schedule during the period of January to March 2019. The findings revealed that BARI rosun-2 had the highest adoption rate among farmers, with 45% choosing this variety, while the adoption rate for BARI rosun-1 was the lowest at 14.67%. Interestingly, no adoption of the other two BARI varieties, BARI rosun-3 and BARI rosun-4, was observed in the study areas. Some farmers also cultivated local and exotic varieties, such as Italy, Patna, and Barma. The preference for BARI rosun-2 and BARI rosun-1 was attributed to their higher yield, greater profitability, and reduced susceptibility to insect-pest infestations at the farm level. Key cost items included human labor, seed cost, and the rental value of land. In terms of yield, the highest production was reported in Rajbari at 7,650 kg per hectare, followed by Natore (7,260 kg/ha.) and Dinajpur (6,980 kg/ha). Net returns were highest in Natore at BDT 69,631 and lowest in Dinajpur at BDT 38,613. The benefit-cost ratio (BCR) on the basis of variable cost and total cost were 1.31 and 1.24, respectively. The cost per kilogram based on total cost was BDT 32. The study identified low market prices during the peak season, the non-availability of improved or hybrid seeds, unfavorable weather conditions, and a lack of technical knowledge as major constraints to garlic cultivation. To address these issues, the study recommends measures such as banning excessive imports, introducing high-yielding hybrid varieties, providing hands-on training to interested farmers, and ensuring affordable input prices to promote higher adoption of these garlic varieties.In conclusion, this research sheds light on the adoption, profitability, and challenges of cultivating BARI garlic varieties in the specified districts, offering valuable insights for policymakers, farmers, and stakeholders in the garlic farming industry.

Keywords: crop diversification; agricultural constraints; hybrid seed technology; economic sustainability; crop yield analysis

1. Introduction

Garlic, often referred to as the "stinking rose," holds a special place among the array of spices cultivated in Bangladesh (Upadhyay, 2017). Renowned for its distinctive flavor, diverse culinary and medicinal uses, garlic has emerged as a cornerstone of the country's spice production, consistently ranking at the summit in terms of output (Afrad and Akter, 2020; Akhter *et al*., 2016; Ambiara *et al*., 2016; Islam and Monjil, 2016; Khan *et al*., 2017; Paswan *et al*., 2021; Rana *et al*., 2021; Sabur and Molla, 1993). Yet, despite its prominence, the local production of this essential spice falls short of meeting the burgeoning domestic demand, compelling the nation to turn to international markets for imports (Begum and D'Haese, 2010; Kotler and Gertner, 2002). The year 2015-16 serves as a poignant reminder of this dependency, as Bangladesh imported a staggering 38,219 metric tons of garlic, amounting to a substantial sum of BDT 373.3 million (BBS, 2016). This extensive reliance on garlic imports underscores the pressing urgency and vast scope for augmenting domestic production (Hasan and Khalequzzaman, 2015; Moyazzem and Abdulla, 2015; Rana *et al*., 2021).

The recent surge in garlic prices provides further testament to the importance of bolstering local garlic cultivation (Hasan and Khalequzzaman, 2015; Hasan and Khalequzzaman, 2017). With escalating market prices serving as a wake-up call, it is imperative to explore strategies for reducing the nation's dependence on external sources (Hasan and Khalequzzaman, 2015; Paczka *et al*., 2021; Rana *et al*., 2021). This challenge presents us with two primary avenues for increasing garlic production within Bangladesh including one involves expanding the cultivated area dedicated to garlic, while the other revolves around enhancing the productivity of existing cultivation (Haque *et al*., 2013). However, within the context of a land-scarce nation like Bangladesh, the first option is encountering significant constraints (Saha *et al*., 2020; Vaumik *et al*., 2017). The ever-increasing demand for land in the non-farm sectors, ranging from housing to infrastructure development, is encroaching upon agricultural land at an alarming rate (Haque *et al*., 2013). It is a well-documented fact that approximately 1% of the country's agricultural land is diverted towards non-agricultural purposes on an annual basis (Quasem, 2011).

On the other hand, the agricultural sector in Bangladesh operates at or near its land frontier, leaving little room for the expansion of production through the introduction of new agricultural land (Pingali, 2012; Rahman, 2017). Compounding this challenge is the disconcerting fact that the average yield of garlic in Bangladesh remains strikingly low, hovering at a meager 6.28 tons per hectare, starkly contrasting with the global average (BBS, 2016). Consequently, an alarmingly low yield in garlic cultivation underscores the pressing need for a fundamental shift in our approach towards garlic farming (Haque *et al*., 2013; Jiku *et al*., 2020; Saha *et al*., 2020). It is paramount that we turn our attention towards enhancing the productivity of garlic cultivation by replacing traditional garlic varieties with improved alternatives.

Remarkably, national agricultural research organizations in Bangladesh have dedicated considerable effort and resources to the development of high-yielding, improved garlic varieties (Sunny *et al*., 2018). These improved varieties are not only characterized by their potential for higher yields but also boast attributes that make them more resilient and sustainable in various agro-ecological contexts (Nayak *et al*., 2022; Pretty and Bharucha, 2014; Rebouh *et al*., 2023; van Bueren *et al*., 2018). However, despite these remarkable advancements in garlic breeding and selection, traditional garlic varieties continue to dominate the fields of local farmers (Haque *et al*., 2013; Parreño *et al*., 2023; Shemesh-Mayer and Kamenetsky-Goldstein, 2021). This prevailing paradox raises important questions regarding the factors influencing farmers' choices and the underlying barriers to the widespread adoption of improved garlic varieties.

Garlic, as a high-value cash crop, harbors the potential to significantly boost the income of farmers due to its inherent capacity for substantial yield and market demand (Ansary *et al*., 2020). Yet, despite the immense promise and clear advantages of adopting improved garlic varieties, a substantial number of farmers across the country remain hesitant to embrace these advancements. As a result, the full potential of garlic cultivation in Bangladesh remains unrealized (Haque *et al*., 2013). In light of the outlined challenges and opportunities, this study is designed to assess the adoption and profitability status of BARI released garlic varieties in the fields of farmers, and to delve into the factors that influence the adoption and non-adoption of BARI released varieties and the major constraints experienced by farmers in the cultivation of garlic varieties. This study is underpinned by a commitment to generating insights that can serve as a catalyst for transformative change within the garlic farming landscape of Bangladesh. The findings have the potential to guide policymakers, agricultural researchers, and farmers in optimizing garlic production, increasing economic returns, and ultimately enhancing food security within the nation. The study is positioned to break down the barriers hindering the widespread adoption of improved garlic varieties, unlocking the full potential of this high-value crop and ushering in a new era of prosperity for garlic growers across the country.

2. Materials and Methods

2.1. Ethical approval

Ethical approval was not required for this study.

2.2. Sampling procedure and sample size

The research was undertaken in three distinct districts of Bangladesh, Rajbari, Natore, and Dinajpur (Figure 1).

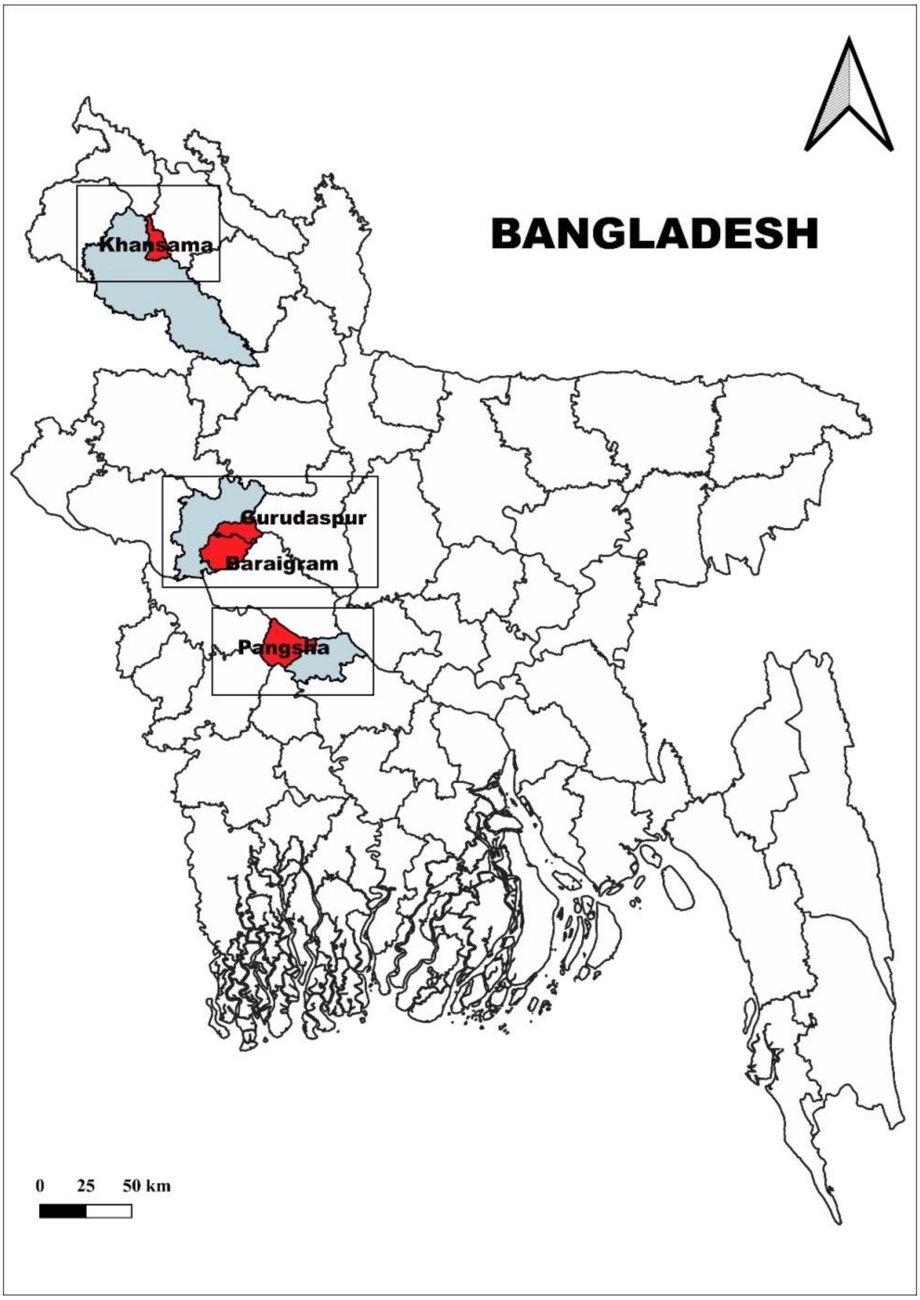

Figure 1. Data were collected from three districts namely, Rajbari, Natore, and Dinajpur.

Within each of these districts, a careful selection process was employed. Specifically, one upazila (sub-district) was thoughtfully chosen from each district, and from each upazila, two blocks were purposively selected in close collaboration with Department of Agricultural Extension (DAE) personnel and garlic experts. Subsequently, the study's sample included a total of 300 farmers, with 100 farmers randomly drawn from each of the three districts (Table 1). Data collection was carried out using a pre-tested interview schedule during the period of January to March 2019.

Table 1. Study areas and respondent farmers.

District	Name of upazila	Name of agril. Block	No of farmers
Rajbari	Pangsha	Patta	50
		Kamardangi	50
Natore	Boroigram	Dharabarisa	50
	Gurudaspur	Boraigram	50
Dinajpur	Khansama	Goyaldihi	50
		Vabki	50
	Total		300

2.3. Data collection

Primary data, encompassing aspects such as farm households, infrastructure, land usage, cropping patterns, adoption rates, input utilization, farm production, grading, packaging, transportation, marketing costs, and cultivation challenges, were gathered through face-to-face interviews with the selected respondents. The data pertaining to the 2018-2019 period were acquired using a survey approach, utilizing a meticulously designed, comprehensive, and pre-tested interview schedule.

2.4. Statistical analytical

The gathered data underwent a process of editing, tabulation, and analysis in order to meet the study's objectives. Descriptive statistics, employing various statistical tools such as means, percentages, and ratios, were employed to present the study's findings. The profitability of garlic production was assessed through the examination of gross returns, gross margins, and the benefit-cost ratio. Additionally, the total cost estimation incorporated the consideration of opportunity costs associated with family-provided labor. Land use costs were computed based on the annual lease value of the land (Haque *et al*., 2013; Islam *et al*., 2016; Meena *et al*., 2013).

2.4.1. Profitability analysis

The profitability of garlic cultivation at the farm level was determined using the subsequent equations for cost analysis,

$$\text{Variable Cost} = \sum_{l=1}^{n} (X\, ijPij)$$

$$TVC_{ij} = VC_{ij} + IOC_{ij}$$

$$TC_{ij} = TVC_{ij} + TFC_{ij}$$

Where, TC_{ij} = Total cost of j^{th} crop for ith farmer (Tk/ha)

TVC_{ij} = Total variable cost of j^{th} crop for i^{th} farmer (Tk/ha).

TFC_{ij} = Total fixed cost of j^{th} crop for i^{th} farmer (Tk/ha)

VC_{ij} = Variable cost of j^{th} crop for i^{th} farmer (Tk/ha)

IOC_{ij} = Interest of operating capital of j^{th} crop for i^{th} farmer (Tk/ha)

X_{ij} = Quantity of inputs of j^{th} crop for i^{th} farmer (kg)

P_{ij} = Price of inputs of j^{th} crop for i^{th} farmer (Tk/kg)

J = Number of crops

i = Number of farmers (1.2.3 ……..n)

Equations for profitability analysis,

$$\text{Gross return} = Gr_{ij} = Y_{ij}P_{ij}$$

$$\text{Net return} = Gr_{ij} - TC_{ij}$$

$$\text{Gross margin} = Gr_{ij} - VC_{ij}$$

Where,

Gr_{ij} = Gross return of j^{th} crop for i^{th} farmer (Tk/ha)

P_{ij} = Price (Tk/ha) of jth crops received by ith farmer

Y_{ij} = Quantity (kg/ha) produced of j^{th} crop for i^{th} farmer.

2.4.2. Factors affecting adoption of garlic technology

To establish the association between garlic adoption and socio-economic factors, we employed the following empirical probit model. The adoption of garlic served as the dependent variable in this model (Akkaya Aslan *et al*., 2007; Khan *et al*., 2022; Sunny *et al*., 2018). The model is outlined as follows,

$$Ai = a + \beta iXi + \ldots\ldots\ldots\ldots + Ui$$

Where,

Ai = Farmers adopting improved garlic (If adopt = 1; Otherwise = 0)
a = Intercept
Xi = Explanatory variables (socioeconomic characteristics)
Bi = Coefficients of respective factors
Ui = Error term

The adoption of garlic is likely to be influenced by the following explanatory variables,

X_1 = Age of the respondent (year)
X_2 = Education (Year of schooling)
X_3 = Farm size (decimal)
X_4 = Family labour (No./ha)
X_5 = Training received on garlic (No. in life time)
X_6 = Training received on agriculture (No. in life time)
X_7 = Availability of seed (Score)
X_8 = Availability of suitable land (Score)
X_9 = Influence of neighboring farmers (Score)
X_{10}= Influence of extension personnel (Score)
X_{11}= Societal membership (Score)

3. Results and Discussion

3.1. Socio-economic profile of the respondent farmers

3.1.1. Education

In this study, the literacy status of the participating farmers was categorized into five distinct groups based on their educational levels including illiterate, primary education, secondary education, higher secondary education, and degree and above. It is noteworthy that 15.67% of the adopters and 20% of the non-adopters had not received any formal education. The majority of adopters, comprising 41.67%, possessed a secondary level education, while 31% had completed their primary education. A smaller percentage, 8.67%, had received a higher secondary education, and 4% held a degree or higher educational qualifications. In contrast, among the non-adopters, 35% had completed their primary education, with an additional 29% having attained a secondary level education. Furthermore, 10% of non-adopters had a higher secondary education, and 4% possessed a degree or higher level of education (Table 2). These findings emphasize the significant role of education in shaping the adoption patterns among farmers and highlight the potential benefits of enhancing educational opportunities within the agricultural sector (Johnson *et al*., 2023; Rizzo *et al*., 2023; Ruzzante *et al*., 2021). Education among farmers is widely anticipated to have a positive impact on agricultural output (Paltasingh and Goyari, 2018; Villar *et al*., 2023). This influence can stem from both formal and informal educational backgrounds, as it plays a crucial role in driving the adoption of new technologies and optimizing the utilization of farm resources to maximize profitability (Bukchin and Kerret, 2020; Martínez-Peláez *et al*., 2023; Udimal *et al*., 2017). The significance of education is underscored by the fact that it is an essential factor in agricultural development.

Table 2. Percent distribution of respondent farmers by literacy levels.

Literacy level	Rajbari	Dinajpur	Natore	All area
A. Adopter				
Illiterate	12	20	15	15.67
Primary	31	30	32	31
Secondary	44	40	41	41.67
Higher secondary	8	10	8	8.67
Degree and above	5	3	4	4

Table 2. Contd.

Literacy level	Rajbari	Dinajpur	Natore	All area
B. Non-adopter				
Illiterate	22	17	21	20
Primary	38	31	38	35.67
Secondary	34	31	24	29.67
Higher secondary	6	14	12	10.67
Degree and above	-	7	5	4.33

3.1.2. Land holding

It becomes evident that adopters and non-adopters had average farm sizes of 1.721 hectares and 1.590 hectares, respectively. Notably, farmers in the Natore district, known for their adoption of new technologies, exhibited larger land holdings compared to their counterparts in Dinajpur and Rajbari districts (Table 3). This variation in farm size can have implications for the adoption and implementation of innovative agricultural practices (Hu *et al*., 2022; Rizzo *et al*., 2023; Sarker *et al*., 2021). The extent of land under the control of farmers plays a pivotal role in determining their agricultural activities. Farm size is quantified as the total land area managed by the farmers, encompassing the land they own, the land they lease from others, and subtracting any land they rent out to others (Dhanaraju *et al*., 2022; Hu *et al*., 2022).

Table 3. Category of land and farm size of the respondent farmers.

Land category	Rajbari	Dinajpur	Natore	All area
A. Adopter				
1. Own land	0.55	0.405	0.348	0.478
2. Rented in	0.66	0.138	0.162	0.181
3. Rented out	0.08	0.101	0.146	0.143
4. Mortgaged in	0.25	0.085	0.121	0.170
5. mortgaged out	0.16	0.093	0.097	0.139
6. Homestead	0.06	0.097	0.101	0.100
7. Garlic land	0.11	0.202	0.223	0.290
9. Fallow land	0.004	0.109	0.081	0.144
10. Pond	0.17	0.081	0.097	0.059
Farm size	1.564	1.794	1.806	1.721
B. Non-adopter				
1. Own land	0.421	0.202	0.308	0.310
2. Rented in	0.162	0.085	0.142	0.130
3. Rented out	0.097	0.057	0.154	0.103
4. Mortgaged in	0.182	0.105	0.113	0.134
5. mortgaged out	0.158	0.097	0.138	0.131
6. Homestead	0.061	0.069	0.081	0.070
7. Garlic land	0.121	0.000	0.000	0.040
8. Orchard	0.745	0.271	0.324	0.447
9. Fallow land	0.028	0.182	0.142	0.174
10. Pond	0	0.093	0.061	0.051
Farm size	1.465	1.162	1.462	1.590

3.1.3. Influencing persons in variety adoption

In the initial phase of adopting BARI garlic varieties, various individuals and sources played a significant role in influencing farmers' decisions. The primary influencers included family members, with the highest influence noted at 42%. Neighboring farmers also exerted substantial influence, with 35% of farmers being influenced by them. Sub-assistant Agricultural Officers (SAAOs) were another influential group, with 25% of farmers receiving guidance from them. Agriculture Officers (AOs) had the least influence in this context, with only 42% of farmers citing them as influential sources. Conversely, the influence of members of Integrated Pest Management/Integrated Crop Management (IPM/ICM) clubs was found to be minimal, with 73% of farmers reporting little to no influence from this group. On the other hand, the most significant influence was attributed to the scientists of the On-Farm Research Division, with 93% of farmers acknowledging their role in the adoption process (Table 4). A number of analogous studies have proposed that the factors influencing the adaptation of new hybrid crop varieties in Bangladesh could stem from a variety of sources (Azad and Rahman, 2017; Mottaleb *et al*., 2015; Sarkar *et al*., 2022).

Table 4. Percent distribution of adopters according to influencing persons.

Persons	Level of influence (%)				
	Very high	High	Medium	Low	No influence
Family member	42	26	13	9	10
Neighbor	35	28	27	5	12
SAAO	25	10	18	22	25
Agriculture Officer	13	18	13	42	16
IPM/ICM club			14	13	73
Scientists of OFRD	-	-	-	7	93

3.1.4. Cropping pattern

Crop selection and planting schemes exhibit variations based on a variety of factors, including the type of land, the category of the farmer (marginal, small, medium, or large), and the Agro-Ecological Zones (AEZ). These differences are primarily driven by climatic conditions, soil characteristics, and the preferences of farmers in crop production. Among the identified cropping patterns, some of the major ones include Garlic-Til-T.aman (19%), Garlic-Vegetable-Vegetable (18%), Garlic-Fellow-T.aman (15%), Garlic-Jute-Fellow (13%), and Garlic-maize-T.aman (12%) (Table 5). In essence, cropping patterns are not uniform and are influenced by a combination of environmental factors, landholding size, and individual farmer preferences (Shukla *et al*., 2019). These patterns reflect the adaptability of agricultural practices to specific conditions, highlighting the need for diversified approaches to crop cultivation in different contexts (Chen *et al*., 2018; Dhanaraju *et al*., 2022; Meuwissen *et al*., 2019).

Table 5. Cropping pattern of garlic farmers in study areas.

Pattern	Rajbari	Dinajpur	Natore	All areas
Garlic-Til-T.aman	19	8	30	19
Garlic-Vegetable-vegetable	15	26	15	18.67
Garlic−Mungbean−T. Aman	10	7	10	9
Garlic-Jute-Fellow	18	12	10	13.33
Garlic-maize-T.aman	5	27	5	12.33
Garlic-T.aus-T.aman	0	3	4	2.33
Garlic-Fellow-T.aman	24	7	15	15.33
Garlic-Jute-T.aman	12	10	9	10.33

3.1.5. Reasons for choosing BARI garlic varieties

The adoption of BARI garlic varieties by farmers in the study areas can be attributed to several appealing characteristics of these varieties. These attributes include their potential for higher yields, strong profitability, robust demand in the market, ready availability of seeds, and reduced vulnerability to insect-pest attacks. Notably, in Dinajpur and Natore, a significant number of respondents (6 from each district) cited the reduced susceptibility to insect-pests as a key reason for their preference for BARI garlic. Additionally, BARI garlic varieties gained popularity among farmers due to their shorter cultivation duration, a factor emphasized by 7 respondents in every district. Interestingly, farmers in Rajbari, in contrast to other districts, highlighted the high heat tolerance of BARI garlic varieties as a key factor in their adoption, with 8 respondents endorsing this attribute (Table 6). In essence, the appeal of BARI garlic varieties lies in their diverse positive qualities, which cater to the specific needs and preferences of farmers in different regions, ranging from insect-pest resistance to adaptability to local climatic conditions (Rahman *et al*., 2020).

Table 6. Reasons for choosing BARI garlic variety adoption.

Reasons	Rajbari	Dinajpur	Natore	All area
Higher yield	1	1	1	1
Highly profitable	2	3	2	2
Less attack of insects and pests	3	6	6	6

Table 6. Contd.

Reasons	Rajbari	Dinajpur	Natore	All area
Availability of seed	4	5	5	5
Cloves size of garlic	5	2	4	3
Higher demand	6	4	3	4
Short duration	7	7	7	7
Heat tolerance	8		-	-

3.1.6. Level of extension contact

When farmers seek information or guidance on technology dissemination and crop-related matters, their initial point of contact is often the Sub-assistant Agricultural Officer (SAAO) of the DAE. Moreover, farmers actively acquire current and relevant knowledge from a variety of sources. These sources include interactions with neighboring farmers, participation in agricultural fairs, visits to demonstration plots, trips to research organizations, exposure to information through television, radio, newspapers, and access to agricultural booklets and leaflets. Notably, approximately 49% of the farmers made contact with extension personnel for information and assistance regarding garlic cultivation, a figure significantly higher than that of non-adopters (Table 7). A relatively higher percentage of adopters had engaged with mass media, such as radio, television, and newspapers, compared to non-adopters in the study areas (Colussi *et al*., 2022; Gao *et al*., 2020; Khan *et al*., 2017; Memon *et al*., 2014). Extension agents and mass media play a crucial role in disseminating knowledge and information related to garlic cultivation and agricultural technologies (Chekol *et al*., 2023; Memon *et al*., 2014; Sunny *et al*., 2018). These sources serve as vital channels for farmers to stay informed, enhance their practices, and make informed decisions in the agricultural domain. The Department of Agricultural Extension (DAE) serves as the primary government agency in Bangladesh responsible for conveying crop-related agricultural innovations from research organizations to the fields of farmers (Ahsan *et al*., 2023; Rahman *et al*., 2020).

Table 7. Level of extension contact of BARI garlic farmers with different extension Medias.

Extension medias	Farmer's responses (%)			
	Frequently	Often	Rarely	Never
A. Adopter				
Extension personnel	27	49	18	6
Neighbor farmer	23	58	17	2
Demonstration plot	3	7	14	76
Participating agril. Fair	-	3	13	84
Television	-	2	4	94
Attend in the field day		8	18	74
Research organization visit	-	4	10	86
Radio	-	6	8	86
News paper	-	-	4	96
Agriculture booklet/leaflet	-	-	1	99
B. Non-adopter				
Extension personnel	18	34	23	25
Neighbor farmer	17	44	7	32
Demonstration plot	6	29	18	47
Participating agril. Fair	2	3	11	84
Television	2	4	17	77
Attend in the field day	-	-	6	94
Research organization visit	--	12	17	71
Radio	-	-	-	100
News paper	-	-	8	92
Agriculture booklet/leaflet	-	-	-	100

3.1.7. Adoption of BARI garlic varieties

In the study areas, farmers exhibit a diverse pattern in their cultivation choices, encompassing a range of varieties, including BARI rosun-1, BARI rosun-2, local varieties, and exotic alternatives such as Italy, Patna, and Barma. Notably, a substantial percentage of farmers, amounting to 45%, opted to cultivate BARI rosun-2 in their fields. This choice was primarily driven by the variety's higher yield and its resistance to diseases and pests. Meanwhile, an average of 14.67% of farmers across all areas adopted BARI rosun-1, which is considered the pioneering variety released from the Spices Research Centre at BARI. However, the newly developed varieties, BARI rosun-3 and BARI rosun-4, failed to find adoption in farmers' fields. Farmers expressed a lack of awareness about these two varieties, and dissemination activities for these particular varieties were conspicuously absent in farmers' fields (Table 8). Alongside these choices, a considerable number of farmers also engaged in the cultivation of local varieties, with an average of 24% of farmers dedicating their fields to some exotic varieties. This pattern of variety selection underscores the diverse and dynamic nature of farmers' preferences, driven by factors such as yield potential, disease resistance, and local knowledge. The characteristics of crop varieties play a pivotal role in shaping farmers' adoption decisions. When these characteristics align with the needs and interests of farmers, the likelihood of adoption increases (Anik and Salam, 2015; Dhivya and Karthikeyan, 2019).

Table 8. Farmer's adoption of different varieties.

Varieties	Percentage of garlic cultivators under different locations			
	Rajbari	Dinajpur	Natore	All areas
BARI rosun-1	14	18	12	14.67
BARI rosun-2	46	38	51	45
BARI rosun-3	-	-	-	-
BARI rosun-4	-	-	-	-
Local varieties	18	24	10	17.33
Exotic varieties	22	20	30	24

3.1.8. Adoption of garlic management technologies

Only a relatively small fraction, constituting 17% of farmers, adhered to the prescribed number of ploughing operations for land preparation. Conversely, a significant majority, averaging 60% of farmers, opted for a seed sowing rate above the recommended levels. Nevertheless, most of these farmers adhered to the recommended timing for sowing, which falls within the last week of October to the first week of November. With regard to planting density, it is observed that 18% of farmers maintained the recommended distance of 10 cm between cloves. However, 52% of farmers chose to plant cloves closer together than recommended, while 28% spaced them farther apart. In terms of irrigation practices, approximately half (50%) of the farmers consistently irrigated their fields as recommended. Additionally, the highest percentage of farmers across all areas, amounting to 75%, followed the prescribed frequency of weeding (2-3 times), contributing to effective weed management. Furthermore, 65% of farmers employed pesticides in their fields to control pests and diseases (Table 9). BARI has put forth a set of improved agricultural practices encompassing various aspects such as tillage operations, seed selection, fertilizer application, weed management, irrigation, and pest control (Alam and Khan, 2017; Tahat *et al*., 2020; Talaviya *et al*., 2020). However, the adoption of these recommended practices among farmers in the study areas exhibits some notable variations. The variations in the adoption of these recommended practices underscore the complexities of farming decisions, influenced by factors such as local conditions, traditional practices, and individual farmer preferences (Rahman *et al*., 2020). While some practices are readily adopted, others face challenges in achieving widespread acceptance among the farming community.

Table 9. Percent of adoption of crop management technologies used in garlic cultivation.

Particular	Rajbari (n=50)	Dinajpur (n=50)	Natore (n=50)	All areas (n=150)	Adoption level
Land preparation					
Recommended ploughing (4-5 times)	18	16	Zero tillage	17	Low
Below recommendation	74	77		75.5	
Above recommendation	8	7		7.5	
Seed rate (kg/ha)					
Recommended (700-1000)	23	24	28	25	Low
Below recommendation	12	14	18	14.67	
Above recommendation	65	62	54	60.33	

Table 9. Contd.

Particular	Rajbari (n=50)	Dinajpur (n=50)	Natore (n=50)	All areas (n=150)	Adoption level
Time of sowing					
Recommended (last Oct. week –first Nov.)	75	72	65	70.67	High
Non-recommended period	25	28	35	29.33	
Cloves to cloves distance					
Recommended **(**10cm**)**	14	18	24	18.67	Low
Below recommendation	58	52	48	52.67	
Above recommendation	28	30	28	28.67	
Deepness of furrow					
Recommended **(75cm)**	86	79	71	78.67	Medium
Below recommendation	3	4	7	4.67	
Above recommendation	11	17	29	19	
No. of irrigation					
Regular irrigation	35	70	45	50	Medium
Not regular irrigation	65	30	55	50	
No. of weeding					
Recommended (2-3 times)	70	77.5	80	75.33	High
Below recommendation	20	10	10	13.33	
Above recommendation	10	12.5	10	10.83	
Non-users					
Insect-pest control					Low
Do not used pesticide	57.5	27.5	20	35	
Used pesticide	42.5	72.5	80	65	

The prescribed fertilizer doses vary depending on the location and time period, reflecting the specific agricultural requirements of each area. However, farmers frequently deviate from these recommendations when it comes to the application of manure and fertilizers (Islam *et al*., 2022a). The adoption of recommended manure doses in various locations was notably low, with a majority of farmers opting to apply quantities below the prescribed levels (Mou *et al*., 2019; Sunny *et al*., 2022). On the other hand, the application of urea exceeded the recommended doses across all areas. In the case of Triple Super Phosphate (TSP), the adoption status was moderate, with a majority of farmers adhering to the recommended doses. In contrast, nearly all the respondent farmers applied Muriate of Potash (MoP) and gypsum in quantities below the recommended levels, indicating a shortfall in the adoption of these practices. Consequently, the utilization of manure and fertilizers, overall, was characterized by low levels of adoption, as the recommended doses were not consistently followed (Table 10). This discrepancy in the application of fertilizers and manure suggests that while some recommendations are met, others face challenges in garnering widespread acceptance among farmers (Islam *et al*., 2022b; Kurniawati *et al*., 2023). Factors such as cost considerations, local soil conditions, and existing agricultural practices may influence these deviations from the recommended doses.

Table 10. Farmer's adoption of different fertilizer dose.

Particular	Rajbari (n=50)	Dinajpur (n=50)	Natore (n=50)	All areas (n=150)	Adoption level
Recommended Cowdung (5 ton/ha)	20	31	18	23	**Low**
Below recommendation	72	62	76	70	
Above recommendation	8	7	6	7	
Recommended Urea (217 kg/ha)	24	29	25	7	**Low**
Below recommendation	12	18	20	16.67	
Above recommendation	64	53	55	57.34	
Recommended TSP (267 kg/ha)	42	38	48	42.67	**Medium**
Below recommendation	26	24	16	22	
Above recommendation	32	38	36	35.33	
Recommended MoP (333 kg/ha)	14	16	24	18	**Low**
Below recommendation	74	80	68	74	
Above recommendation	12	4	8	8	

Table 10. Contd.

Particular	Rajbari (n=50)	Dinajpur (n=50)	Natore (n=50)	All areas (n=150)	Adoption level
Recommended Gypsum (110 kg/ha)	24	42	28	31.33	**Low**
Below recommendation	67	38	72	59	
Above recommendation	9	20	2	10.33	

3.1.9. Determinates of Adoption of BARI garlic varieties

The adoption of BARI garlic varieties at the farm level is subject to influence from various socio-economic factors. These factors include age, education, family labor, experience, training, farm size, the influence of Sub-assistant Agricultural Officers (SAAO), and extension contacts. The coefficients associated with several of these factors, namely farmer's education, training, farm size, availability of suitable land, availability of quality saplings, influence of SAAO, and extension contact, all demonstrated a positive and statistically significant impact on the adoption of BARI garlic varieties in the study areas (Islam *et al*., 2019). Further analysis through marginal effects reveals that an increase of 100% in these factors results in an increased probability of adopting BARI garlic varieties by 4%, 12.42%, 23.89%, 5.32%, 1.5%, 8.6%, 9.6%, and 1.2%, respectively. In essence, these findings indicate that the socio-economic factors mentioned, when enhanced or improved, can significantly contribute to a higher likelihood of farmers adopting BARI garlic varieties, underlining the importance of these variables in influencing adoption behavior (Tables 11 and 12).

Table 11. Maximum likelihood estimates of variable determining adoption of BARI garlic varieties among respondent farmers.

Explanatory variable	Coefficient	Standard error	Z-statistic	Probability *P*>z
Constant	-11.2893***	1.9823	-7.08	0.000
Age(year)	0.0258	0.0235	2.64	0.003
Education (year of schooling)	0.10498 **	0.0062	1.47	0.136
Training on garlic(No. of life time)	0.18925 **	0.0560	1.89	0.016
Farm size (decimal)	0.12652 **	0.1256	2.36	0.036
Family labour (No./year)	0.45784**	0.0654	1.84	0.012
Availability of suitable land (Scale,0-4;0=not available 4= plenty)	0.21354	0.0456	2.38	0.006
Availability of quality seed (Scale,0-4;0=not available 4= plenty)	1.49253 ***	0.1352	4.36	0.038
Influence of neighbor (score) (Scale,0-4;0=not influence 4= high influence)	0.0892	0.0254	3.12	0.632
Influence of SAAO (score) (Scale,0-4;0=not influence 4= high influence)	0.3932**	0.0638	4.23	0.002
Extension contact (score) (Scale,0-4;0=no contact 4=regular contact)	0.02935**	0.0937	2.65	0.005

Table 12. Marginal effect of the variables determining adoption of BARI garlic variety among respondent farmers.

Explanatory variable	dy/dx	Standard Error	Z-statistic	Probability
Age (year)	0.00004	0.0235	2.34	0.009
Education (year of schooling)	0.04003**	0.0062	1.29	0.141
Training on garlic(No. of life time)	0.12426**	0.0560	1.67	0.021
Farm size (decimal)	0.23892**	0.1256	2.89	0.034
Family labour (No./year)	0.05325**	0.0654	1.78	0.017
Availability of suitable land (score)	0.01532	0.0456	2.37	0.007
Availability of quality seed (score)	0.08624***	0.1352	3.98	0.045
Influence of neighbor (score)	0.00364	0.0254	2.89	0.664
Influence of SAAO (score)	0.09604**	0.0638	4.47	0.009
Extension contact (score)	0.01243**	0.0937	2.62	0.008

3.2. Input utilization

The utilization of various inputs plays a crucial role in determining the overall cost of garlic cultivation. Garlic farmers employ a range of inputs, including human labor, machinery, seeds, manure, fertilizers, irrigation, and plant protection measures, to manage their fields effectively (Durán-Lara *et al*., 2020). The application of fertilizers is particularly critical for achieving a bountiful yield, with the required doses varying depending on the garlic variety and the initial soil fertility conditions (Assefa *et al*., 2015; Jiku *et al*., 2020; Kakar *et al*., 2002). In terms of manure application, farmers, on average, utilized 3554 kg per hectare. Human labor played a pivotal role throughout the garlic cultivation process, encompassing activities such as land development, seed sowing, the application of manure and fertilizers, spraying, weeding, irrigation, and harvesting. On average, garlic cultivation necessitated 252 man-days of human labor per hectare, with 40% of this labor being supplied by the farmer's own family, while 60% was hired labor. The application of fertilizers per hectare involved significant quantities, including 382 kg of urea, 224 kg of Muriate of Potash (MoP), 262 kg of Triple Super Phosphate (TSP), 192 kg of Di-ammonium Phosphate (DAP), 64 kg of gypsum, 56 kg of magnesium, 23 kg of boron, and 15 kg of zinc (Islam *et al*., 2020). On average, irrigation was carried out four times during the garlic cultivation process. While farmers implemented various insecticides and pesticides in their fields for pest control, it was observed that they did not adhere to the recommended doses due to a knowledge gap. This discrepancy underscores the need for enhanced knowledge dissemination and training in integrated pest management to improve pest control practices and optimize input utilization in garlic cultivation (Table 13).

Table 13. Input use pattern per hectare for garlic cultivation.

Particulars	Units	Actual utilization level on different locations			
		Rajbari	Dinajpur	Natore	All areas
Human labour	man days	280	290	185	252
Family labour	man days	120	130	54	101
Hired labour	man days	190	175	103	156
Seed	Kg	541	521	480	514
Manures	Kg	3956	4835	1871	3554
Ash	Kg	3872	4560	3742	4058
Dolomite	Kg	172	170	187	176
Urea	Kg	378	395	374	382
MoP	Kg	125	247	299	224
TSP	Kg	250	247	290	262
DAP	Kg	38	247	290	192
Gypsum	Kg	57	99	37	64
Zinc	Kg	11	20	14	15
Magnesium	Kg	54	54	59	56
Boron	Kg	25	19	24	23
Irrigation	No.	3	5	4	4
Insecticides and pesticides	No.	2	2	2	2
Growth hormone	No.	1	0	1	0.67

3.2.1. Cost and return of garlic production

Planting materials, land preparation, input cost (FYM, fertilizers, plant growth regulators, plant protection chemicals etc.), labour cost, power cost, harvesting, packing and transportation charges were the main cost components for garlic cultivation (Islam *et al*., 2021). Rental value of land was treated as fixed cost and interest on operating capital was also considered for the estimation of garlic cultivation cost. On average farmers spend Tk. 6300/ha for land preparation by using power tiller/tractor. The highest manures cost was observed Tk. 2417/ha at Dinajpur followed by Rajbari (Tk. 1978/ha), and Natore (Tk. 935/ha). Per hectare average seed cost was Tk. 35980 which was the highest in Rajbari (Tk.) and lowest in Natore (Tk 33600). Among variable costs human labour cost was the highest in all study areas. The highest human labour cost was observed (Tk. 112000/ha) at Rajbari and lowest (Tk. 64750/ha) in Natore (Islam *et al*., 2021). The overall rental value of land was Tk. 12000/ha. For four months. The interest on fixed cost and interest on operating cost was calculated @ of 8% basis. Among three locations the highest total cost was found Tk. 242823/ha at Rajbari and lowest in Natore Tk. 220768/ha (Table 14).

Table 14. Per hectare garlic cost of production in different locations.

Cost heading	Rajbari	Dinajpur	Natore	All areas	% of total cost
Human labour*	112000	101500	64750	92750	39.51
Family labour	42000	42000	64750	49583	21.12
Hired labour	70000	59500	33250	54250	23.11
Land preparation	6736	5864	-	6300	2.68
Seed	37870	36470	33600	35980	15.33
Manures	1978	2417	935	1777	0.76
Ash	1936	2280	1871	2029	0.86
Dolomite	3440	3400	3740	3520	1.50
Urea	6048	6320	5984	6112	2.61
MoP	2000	3952	4784	3584	1.52
TSP	9000	8892	10440	9432	4.02
DAP	1520	9880	11600	7680	3.27
Gypsum	1368	2376	888	1536	0.66
Zinc	2200	4000	2800	3000	1.28
Magnesium	1620	1620	1770	1680	0.71
Boron	2000	1520	1920	1840	0.77
Irrigation	14821	12564	9625.00	23648	5.26
Growth hormone	4940	4832	14	3262	1.39
Insecticides and pesticides	4363	3654	4356.00	17192	1.76
Transportation	2350	1980	1832	2054	0.88
Miscellaneous expense	5460	5892	5436	5154	2.20
Interest on operating capital	9173	9173	9173	9173	3.91
Total variable cost	230823	228586.5	208768.5	222726	94.89
Rental value of land	12000	12000	12000	12000	5.11
Total cost	242823	240586.5	220768	234726	100

3.3. Profitability of garlic cultivation

The cost components associated with garlic cultivation were diverse and encompassed various aspects of the agricultural process (Islam *et al*., 2021). These cost components included expenses related to planting materials, land preparation, input costs (covering farmyard manure, fertilizers, plant growth regulators, and plant protection chemicals), labor costs, power costs, harvesting, packing, and transportation charges. Additionally, the cost estimation for garlic cultivation considered the rental value of land as a fixed cost, and it factored in the interest on operating capital. In terms of specific costs, the average expenditure on land preparation stood at Tk. 6300 per hectare, utilizing power tillers or tractors. Manure costs exhibited variations across the study areas, with the highest observed in Dinajpur at Tk. 2417 per hectare, followed by Rajbari at Tk. 1978 per hectare, and Natore at Tk. 935 per hectare. For seed expenses, the per-hectare average amounted to Tk. 35980, with the highest cost noted in Rajbari and the lowest in Natore. Among the variable costs, labor costs were the most substantial across all study areas. In particular, Rajbari incurred the highest human labor cost at Tk. 112000 per hectare, while Natore had the lowest at Tk. 64750 per hectare. The overall rental value of land was estimated at Tk. 12000 per hectare for a four-month period. To calculate the cost more comprehensively, both the interest on fixed costs and the interest on operating costs were considered, with an 8% interest rate applied. Comparing the total costs among the three locations, it was found that Rajbari had the highest total cost, amounting to Tk. 242823 per hectare, while Natore had the lowest total cost at Tk. 220768 per hectare. These findings provide a comprehensive overview of the cost dynamics involved in garlic cultivation, emphasizing the variations in cost components and their impact on the overall cost of production in different locations (Table 15).

Table 15. Summary results of costs, returns and profitability of garlic at different locations.

	Particulars	Rajbari	Dinajpur	Natore	All areas
1	Yield (kg)	7650	6980	7260	7296
2	Price (Tk./kg)	40	40	40	40
3	Gross return (Tk.)	306000	279200	290400	291866
4	Gross costs (Tk.)	242823	240586	220768.5	234726
5	Variable costs (Tk.)	230823	228586	208768.5	222726
6	Gross margin (Tk.)	75177	50613	81631	69140

Table 15. Contd.

	Particulars	Rajbari	Dinajpur	Natore	All areas
7	Net return (Tk.)	63177	38613	69631	57140
8	Benefit-cost ratio (Variable cost basis)	1.33	1.22	1.39	1.31
9	Benefit-cost ratio (Total cost basis)	1.26	1.16	1.32	1.24
10	Cost per unit output (Variable cost basis)	30	33	29	31
11	Cost per unit output (Total cost basis)	32	34	30	32

3.4. Problems and constraints to garlic cultivation

While garlic cultivation offers the promise of profitability, farmers in the study areas faced a spectrum of challenges and constraints in the production process. These constraints were systematically ranked based on the frequencies of responses (Islam *et al*., 2018). The findings underscored that a significant proportion, a notable 84% of farmers, regarded the low market price of garlic during the peak season as their primary challenge. This problem was further exacerbated by the considerable annual fluctuations in garlic prices, resulting in substantial losses for farmers. Farmers attributed the decline in market prices to the substantial influx of imported garlic into the local market. Furthermore, approximately 83.5% of farmers pointed out that the improved garlic varieties developed by BARI were not readily available in their local markets (Table 16). Moreover, 58% of farmers expressed that other crops were more financially rewarding than garlic cultivation, leading to a decline in the cultivation of garlic. Unfavorable weather conditions, limited access to technical knowledge, a lack of institutional loans, and a dearth of guidance and encouragement from local administrative bodies were also cited as constraints to garlic production in Bangladesh (Fakir *et al*., 2021; Hoque *et al*., 2022). These constraints collectively highlight the multifaceted challenges faced by garlic farmers, encompassing market-related issues, competition from other crops, and a range of structural and knowledge-related challenges. Addressing these constraints is critical to sustaining and enhancing the profitability of garlic cultivation in the region.

Table 16. Constraints faced by farmers at different locations.

Constraints	% farmers responded			
	Rajbari	Dinajpur	Natore	All areas
Low market price of garlic at peck season	80	85	86	84.0
Non availability of improved/HYV seed	70	90	89	83.5
Competitive crop more profitable	65	60	50	58
Unfavorable weather condition	28	34	24	28.67
Lack of technical know-how for garlic cultivation	70	76	74	73
Non-availability of institutional loan	60	80	60	71.3
No direction and encouragement from local administration for garlic cultivation	60	63	72	61.3

4. Conclusions

This study has shed light on the critical nexus of production practices, adoption status, and profitability in the context of BARI garlic cultivation, underscoring its pivotal role in achieving self-sufficiency in Bangladesh's garlic production. While the profitability indicators, including gross margin, net margin, and benefit-cost ratio, affirm that farmers across the country stand to gain from cultivating BARI garlic varieties, the low adoption of management technology represents a substantial research gap. Despite the economic viability of garlic cultivation, farmers grapple with various challenges, including the unavailability and high cost of quality seeds, limited technical knowledge, price volatility, unfavorable weather conditions, and rising production costs. These findings underscore the need for future research to delve deeper into the reasons behind the low adoption of management technology and to propose innovative solutions to mitigate the challenges faced by garlic cultivators. Additionally, future studies could explore the impact of policy interventions in promoting the widespread adoption of BARI garlic varieties and the implications for achieving self-sufficiency in garlic production.

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Data availability
The data used to support the findings of this study are included within the article.

Conflict of interest
None to declare.

Authors' contribution
Conceptualization: [Md. Imrul Kaysar], [Syful Islam]; Methodology: [Md. Imrul Kaysar], [Syful Islam] [Monirul Islam], [Sohag Sarker]. Data collection and formal analysis: [Md. Imrul Kaysar], [Monirul Islam], [Nusrat Binta Atiq]; Writing - original draft preparation: [Md. Imrul Kaysar] [Syful Islam]; Writing - review and editing: [Md. Imrul Kaysar], [Syful Islam]. All authors have read and approved the final manuscript.

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