Technical Efficiency and Production Constraints in Cotton Cultivation: An Empirical Analysis of Hybrid and Local Varieties in Kushtia, Bangladesh

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ABSTRACT

This study investigates the technical efficiency and production constraints of hybrid and local cotton varieties in Kushtia district, Bangladesh, using primary survey data from 60 farmers (30 hybrid and 30 local). A Cobb–Douglas stochastic frontier production function was applied to estimate technical efficiency and identify determinants of inefficiency. Results indicate that hybrid cotton farmers achieved a mean technical efficiency of 92 percent, compared with 81 percent for local farmers, implying potential output gains of 8 and 19 percent, respectively, under existing input levels. For hybrid cotton, human labor, TSP, gypsum, and irrigation exerted significant positive effects on production, while urea showed a negative impact. Farm size, training, and farming experience were found to significantly reduce inefficiency. Local cotton farmers exhibited similar patterns, with human labor, TSP, and irrigation positively influencing yield. The analysis further identified key production constraints, including long cultivation duration (91.67 percent of farmers), low output prices (90 percent), insect infestations (83.33 percent), and adverse climatic conditions (75 percent). These findings suggest that targeted interventions—such as farmer training, improved resource management, expansion of farm size, and strategies to address systemic production constraints—can enhance cotton productivity and efficiency. Strengthening these areas could reduce Bangladesh's heavy reliance on cotton imports and support the long-term sustainability of its textile sector.

Keywords: Cotton production, technical efficiency, stochastic frontier analysis, production constraints, Kushtia district, Bangladesh.

INTRODUCTION

Cotton (Gossypium hirsutum) occupies a pivotal position in Bangladesh's agricultural economy as the second most important cash crop after jute (Uddin and Mortuza, 2015). The textile and clothing industries, which are heavily dependent on cotton fibers, constitute the largest manufacturing subsector in Bangladesh's economy, contributing significantly to employment generation and export earnings (Dristy et al., 2024). Despite Bangladesh's prominent global position as the fifth-largest raw cotton consumer and second-largest apparel producer, the country faces a critical supply–demand imbalance, producing only 2–3% of its cotton requirements domestically while importing approximately 97% from countries including Uzbekistan, India, Pakistan, and Turkmenistan (Uddin and Mortuza, 2015; Nadiruzzaman et al., 2019).

Bangladesh's annual cotton demand has experienced substantial growth, reaching 8 million bales in 2018, while domestic production stagnates at approximately 150,000 bales (Nadiruzzaman et al., 2021). This striking disparity between supply and demand imposes a significant economic burden on the country, costing 12–15 thousand crore Taka annually in import expenditures. In response to this challenge, the Cotton Development Board (CDB) has established an ambitious target to produce 2.5 lakh bales by 2021, which would satisfy nearly 5–7% of the annual domestic demand and contribute to reducing import dependency.

Cotton cultivation in Bangladesh currently covers approximately 42,000 hectares distributed across 35 districts, with Kushtia emerging as a major production hub (Nadiruzzaman et al., 2021). Two principal types of cotton are cultivated: American upland cotton (Gossypium hirsutum) on plains and hill cotton (Gossypium arboreum) on Chittagong Hill Tracts. The CDB has developed and released 14 upland cotton varieties (CB-1 to CB-14), with CB-12, CB-13, and CB-14 being high-yielding varieties exhibiting favorable fiber characteristics suitable for the textile industry.

Technical efficiency, which is conceptually defined as the ability to produce maximum feasible output from a given set of inputs and available technology (Farrell, 1957; Koopmans, 1951), represents a crucial determinant of agricultural productivity enhancement. Improving technical efficiency enables farmers to increase output without requiring additional resource investments, thereby enhancing profitability and competitiveness (Debreu, 1951). In resource-constrained agricultural systems characteristic of developing countries, understanding efficiency levels and their determinants becomes paramount for designing effective policy interventions (Biswas et al., 2022; Majumder et al., 2020).

While several studies have examined cotton profitability and production economics in Bangladesh (Biswas, 1992; Rahman et al., 2013; Rahman et al., 2018), comprehensive analyses of technical efficiency employing stochastic frontier methods remain conspicuously limited. The literature gap is particularly pronounced regarding comparative efficiency analysis between hybrid and local cotton varieties, which differ substantially in their input responsiveness, management requirements, and yield potential. Understanding variety-specific efficiency levels, identifying factors contributing to technical inefficiency, and documenting production constraints faced by farmers are essential for policymakers and agricultural extension services to design targeted interventions capable of increasing domestic cotton production and reducing import dependency.

Moreover, contemporary challenges, including climate variability, pest pressure, input price volatility, and labor availability constraints, necessitate evidence-based strategies for sustainable cotton production intensification (Nadiruzzaman et al., 2019; Dristy et al., 2024). The imperative to enhance domestic cotton production while maintaining economic viability and environmental sustainability underscores the importance of efficiency-oriented research.

Against this backdrop, the present study aims to (1) estimate the technical efficiency of hybrid and local cotton production via stochastic frontier analysis; (2) identify and quantify factors affecting technical inefficiency in both production systems; and (3) document and prioritize major production constraints faced by cotton farmers in the Kushtia district. The findings are expected to provide actionable intelligence for agricultural policymakers, extension services, and cotton development programs seeking to increase domestic cotton production efficiency and competitiveness.

LITERATURE REVIEW

Theoretical Framework Of Technical Efficiency

The conceptual foundation of productive efficiency was established by Farrell (1957), who decomposed economic efficiency into technical and allocative components. Technical efficiency refers to a firm's ability to obtain maximal output from a given set of inputs, whereas allocative efficiency reflects the ability to use inputs in optimal proportions given their respective prices and production technology (Farrell, 1957; Koopmans, 1951; Debreu, 1951). Farrell's seminal work provided the theoretical basis for empirical efficiency measurement, which has since evolved through parametric and nonparametric approaches.

The stochastic frontier production function approach, independently introduced by Aigner et al. (1977) and Meeusen and van den Broeck (1977), revolutionizes efficiency measurement by explicitly distinguishing between random noise (beyond farmers' control) and technical inefficiency (within farmers' control). This methodological innovation addresses a fundamental limitation of deterministic frontier approaches by accommodating measurement errors, weather shocks, and other stochastic factors affecting agricultural production (Jondrow et al., 1982). The stochastic frontier approach has consequently become the predominant method for measuring the technical efficiency of agricultural systems worldwide.

Technical efficiency in cotton production

Global cotton production efficiency has received considerable research attention because of the economic importance and input-intensive cultivation requirements of cotton. Odedokun (2014) analyzed cotton production efficiency in Zamfara State, Nigeria, employing stochastic frontier analysis to reveal a mean technical efficiency of 0.67, indicating potential output increases of 23% through improved management practices without additional input investments. The study identified farm size, education, and extension contact as significant efficiency determinants, emphasizing the role of human capital in enhancing agricultural productivity.

In the context of genetically modified cotton adoption, Bennett et al. (2004) documented substantial financial benefits for smallholder Bt cotton growers in South Africa, attributable to increased yields and reduced insecticide costs. Their analysis revealed that Bt cotton technology generated efficiency gains through reduced pesticide application and associated labor savings. Similarly, Loganathan et al. (2009) examined the productivity and profitability impacts of Bt cotton cultivation in Tamil Nadu, India, and reported that genetically modified varieties significantly enhanced the technical efficiency through superior pest resistance and yield stability. Parameswaran and Cayalvizhi (2020) further demonstrated that fertilizer management, Bt technology, and insecticide application contributed 60%, 23%, and 17%, respectively, to Bt cotton yield increases in India from 2000--2014, underscoring the multifaceted nature of efficiency enhancement.

Cotton Production Research in Bangladesh

Research on cotton production in Bangladesh has evolved from descriptive analyses to more sophisticated economic evaluations. Biswas (1992) conducted pioneering work identifying major problems in cotton cultivation in Jessore District, documenting constraints including the nonavailability of quality seeds, excessive input costs, inadequate technical knowledge among farmers, and limited access to credit facilities. These foundational insights established the baseline understanding of production constraints affecting Bangladeshi cotton farmers.

Rahman et al. (2013) undertook a comprehensive profitability analysis of major crops in Bangladesh, including cotton, finding that cotton cultivation remained economically viable under proper management despite facing numerous production challenges. The benefit–cost ratio analysis revealed positive returns to cotton investment, although profitability varied substantially across different production systems and agroecological zones. Rahman et al. (2018) subsequently examined the productivity and profitability of improved versus existing cropping patterns in the Kushtia region, highlighting the potential contribution of cotton to income diversification and agricultural intensification.

More recently, Nadiruzzaman et al. (2019) conducted value chain analysis of climate-resilient cotton production in Bangladesh, emphasizing the critical importance of improved varieties and adaptive management practices for sustaining production under increasingly variable climatic conditions. Their work highlighted systemic constraints extending beyond farm-level production, including postharvest handling, marketing infrastructure deficiencies, and price volatility challenges. Dristy et al. (2024) further examined sustainable practices for cotton production from economic and environmental perspectives, suggesting integrated approaches that balance productivity enhancement with ecological sustainability concerns.

Despite these valuable contributions, systematic technical efficiency analysis employing stochastic frontier methods remains limited in Bangladesh's cotton production literature. Biswas et al. (2022) applied stochastic frontier analysis to maize cultivation in Bangladesh, demonstrating the approach's utility for identifying efficiency gaps and improvement opportunities, but comparable analyses for cotton production are lacking.

Input Productivity and Resource Use Efficiency

Extensive research on input productivity in cotton production has identified human labor, fertilizers, and irrigation as primary determinants of yield variation. Ramamoorthy (1990) examined the economics of cotton production in India, highlighting labor intensity as a distinguishing characteristic affecting profitability and competitiveness. Reddy et al. (1997) conducted a comparative economic analysis of cotton cultivation in the Guntur district, Andhra Pradesh, and reported significant yield responsiveness to phosphatic fertilizers and irrigation applications.

The Cobb–Douglas production function has been widely employed to quantify input–output relationships in cotton production systems. These studies consistently demonstrate that balanced fertilizer application, adequate irrigation, and timely labor availability constitute critical determinants of cotton productivity (Ramamoorthy, 1990; Reddy et al., 1997). However, research has also revealed instances of overapplication of fertilizer, particularly nitrogen, leading to diminishing returns and environmental externalities (Parameswaran and Cayalvizhi, 2020).

Determinants of Technical Inefficiency

Empirical studies have identified diverse socioeconomic and farm-specific factors influencing the technical inefficiency of agricultural production. Farm size has been consistently associated with efficiency levels, although the relationship direction varies across contexts. Larger farms often exhibit greater efficiency due to economies of scale, better resource access, and enhanced management capacity (Odedokun, 2014). However, some studies report superior efficiency among smaller farms attributable to intensive management and family labor utilization.

Human capital variables, particularly education, training, and farming experience, have demonstrated significant effects on technical efficiency. Educated farmers typically exhibit greater receptivity to technological innovations and improved management practices (Biswas et al., 2022; Majumder et al., 2020). Agricultural training programs enhance farmers' technical knowledge and decision-making capabilities, directly contributing to efficiency improvement. Similarly, farming experience facilitates learning-by-doing processes, enabling farmers to optimize resource allocation over time.

Farmer age has shown mixed effects on efficiency across different studies. While younger farmers may demonstrate greater innovation adoption propensity, older farmers often possess accumulated tacit knowledge valuable for production management. Extension service access and market proximity have also emerged as significant determinants of efficiency, affecting farmers' information access and input–output market integration (Nadiruzzaman et al., 2019).

Production Constraints in Cotton Cultivation

Cotton production faces multifaceted constraints ranging from biophysical challenges to market and institutional limitations. Pest and disease pressure, particularly from lepidopteran pests and boll rot infections, represents a persistent challenge, causing substantial yield losses and escalating production costs (Bennett et al., 2004; Loganathan et al., 2009). Climate variability, including erratic rainfall patterns, drought stress, and extreme temperature events, increasingly threatens cotton production stability (Nadiruzzaman et al., 2019; Dristy et al., 2024).

Market-related constraints, including price volatility, limited storage infrastructure, and weak farmer bargaining power, undermine economic viability and discourage production expansion (Uddin and Mortuza, 2015). Input market imperfections, characterized by quality adulteration, supply chain inefficiencies, and price fluctuations, further complicate production management. Institutional constraints, including inadequate extension services, limited credit access, and insufficient research-extension-farmer linkages, impede technology adoption and efficiency improvement (Biswas, 1992; Nadiruzzaman et al., 2019).

Recent studies emphasize the importance of integrated approaches addressing production constraints holistically rather than in isolation. Garbole (2025) demonstrated in Ethiopian agriculture that sustainable intensification requires simultaneous attention to agrobiodiversity conservation, input optimization, and farmer knowledge enhancement. Similarly, contemporary cotton research advocates for systems-oriented interventions that combine improved varieties, precision nutrient management, integrated pest management, climate risk mitigation, and value chain development (Dristy et al., 2024).

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Research Gap and Study Design

Despite substantial global literature on cotton production efficiency, significant gaps persist in understanding the determinants of technical efficiency in Bangladesh's cotton sector. Existing studies have focused primarily on profitability analysis and general production constraints, with limited application of stochastic frontier methods for rigorous efficiency measurement. The comparative efficiency analysis between hybrid and local cotton varieties remains unexplored, despite varieties' potentially divergent input responsiveness and management requirements.

Furthermore, previous constraint assessments have been largely descriptive, lacking systematic prioritization on the basis of farmer perceptions and impact severity. The interaction between technical efficiency levels and specific production constraints requires further investigation to inform targeted intervention design. Additionally, variety-specific inefficiency determinants need to be identified to enable differentiated extension strategies appropriate for hybrid and local cotton production systems.

The present study addresses these gaps by providing a comprehensive stochastic frontier analysis of the technical efficiency of both hybrid and local cotton varieties, identifying variety-specific inefficiency determinants, and systematically documenting and prioritizing production constraints. The findings contribute empirical evidence supporting policy formulation and program design aimed at enhancing domestic cotton production efficiency and reducing import dependency, thereby advancing Bangladesh's agricultural development and textile industry competitiveness.

METHODOLOGY

Study Area and Sampling

The study was conducted in Kushtia district, which is located in the southwestern region of Bangladesh (23°42' to 24°12' N latitude and 88°42' to 89°22' E longitude). Three upazilas—Bheramara, Daulatpur, and Mirpur—were purposively selected on the basis of high cotton production concentration, homogeneous soil and climatic conditions, and accessibility.

A purposive random sampling technique was employed. From a sampling frame of 250 cotton farmers purposive random sampling technique was employed. From a sampling frame of 250 cotton farmers provided by the Department of Agricultural Extension (DAE), 100 were identified as small farmers (0.05--2.49 acres) with a minimum of three years of cotton cultivation experience. Sixty farmers were randomly selected: 30 cultivating hybrid varieties (CB-10, CB-11, CB-12) and 30 cultivating local varieties.

Table 1: Sample distribution

SL. No.	Variety	Number of Respondents
1	Hybrid	30
2	Local	30
Total		**60**

Source: Field Survey

Data collection

Primary data were collected from March 1 to April 15, 2020, through face–to–face interviews via a pretested structured questionnaire. The survey schedule covered the following:

- General and sociodemographic information
- Farm holding status
- Cotton production details (inputs and outputs)
- Farmers' perceptions and constraints

Multiple visits were conducted to ensure data reliability, particularly since farmers did not maintain formal records. Inconsistencies were verified through neighboring farmers.

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ANALYTICAL FRAMEWORK

Stochastic Frontier Production Function

The Cobb–Douglas stochastic frontier production function was specified as follows:

$$\ln Y = \ln \alpha + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + \beta_6 \ln X_6 + \beta_7 \ln X_7 + (Vi - Ui)$$

where:

- Y = Gross return per hectare (Tk/ha)
- ln α = Intercept
- X_1 = Cost of human labor (Tk/ha)
- X_2 = Cost of urea (Tk/ha)
- X_3 = Cost of the TSP (Tk/ha)
- X_4 = cost of MoP (Tk/ha)
- X_5 = Cost of gypsum (Tk/ha)
- X_6 = cost of irrigation (Tk/ha)
- X_7 = Cost of insecticide (Tk/ha)
- $\beta_1 ... \beta_7$ = Coefficients to be estimated
- Vi = random error term, $N(0, \sigma_v^2)$
- Ui = Technical inefficiency effect, $|N(0, \sigma_u^2)|$

Technical Inefficiency Model

The effects of technical inefficiency were modeled as follows:

$$Ui = \delta_0 + \delta_1 Z_1 + \delta_2 Z_2 + \delta_3 Z_3 + \delta_4 Z_4 + \delta_5 Z_5 + \delta_6 Z_6 + Wi$$

where:

- Z_1 = Farm size (hectares)
- Z_2 = Respondent age (years)
- Z_3 = Respondent education (years)
- Z_4 = training (1 if received, 0 otherwise)
- Z_5 = Cotton farming experience (years)
- Z_6 = Market distance (km)
- Wi = Random variable with positive half-normal distribution

The model was estimated simultaneously via STATA software with maximum likelihood estimation.

RESULTS AND DISCUSSION

Sociodemographic profile

Table 2: Average Family Size and Distribution by Sex

Particulars	Bheramara Upazila		Daulatpur Upazila		Mirpur Upazila		All Farmers		National Average
	Number	Percent	Number	Percent	Number	Percent	Number	Percent	Family Size
Male	3.56	62.24	3.15	53.94	2.97	53.23	3.23	56.47	4.06
Female	2.16	37.76	2.69	46.06	2.61	46.77	2.49	43.53	
Total	5.72	100	5.84	100	5.58	100	5.72	100	

Source: Field Survey

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The average family size of the cotton farmers was 5.72 persons, which was slightly above the national average of 4.06. Male members constituted 56.47% of the household members. The primary age group was 20--40 years (52%), indicating active working-age farmers. In terms of educational attainment, 41.7% had secondary or higher secondary education, whereas 8.3% had graduation-level education, as described in Table 2.

Table 3: Agricultural Work and Income Sources

Sector	Average Annual Income (Tk)
Crops	60,897.87
Poultry	34,989.80
Livestock	36,800.00
Fisheries	25,678.00
Mean Agricultural Income	**158,365.67**
Non-Agricultural Income	**105,171.40**
Total Average Annual Income	**263,537.07**
Average Annual Expenditure	**220,989.60**
Average Annual Savings	**42,547.00**

Source: Field Survey

Table 3 shows that agricultural activities, particularly crop production, constituted the primary income source. The average annual household income was Tk. 263,537.07, with savings of Tk. 42,547 annually.

Table 4: Agricultural training and organizational membership

Indicator	Bheramara		Daulatpur		Mirpur		All Farmers	
	No.	%	No.	%	No.	%	No.	%
Received Training	18	90	17	85	17	85	52	86.7
Organization Member	15	75	16	80	12	60	43	71.7

Source: Field Survey

Table 4 shows that 86.7% of the farmers received cotton cultivation training, primarily from the Cotton Development Board (CDB) and Bangladesh Agricultural Development Corporation (BADC). This high degree of training participation suggests good extension service coverage in the study area.

Stochastic Frontier Production Function Results

Hybrid Cotton Production

Table 5: ML estimates for the Cobb–Douglas stochastic frontier production function - hybrid cotton

Variables	Parameter	Coefficients	T-ratio
Stochastic Frontier:			
Constant (X_0)	β_0	6.38**	2.05
Human Labor (X_1)	β_1	0.6774**	2.21
Urea (X_2)	β_2	-0.3483***	-3.40
TSP (X_3)	β_3	0.7819***	4.10
MoP (X_4)	β_4	-0.1930	-0.37
Gypsum (X_5)	β_5	0.2310***	3.78
Irrigation (X_6)	β_6	0.0970***	3.71
Insecticide (X_7)	β_7	-0.05232	-0.11
Inefficiency Model:			
Constant	δ_0	-5.46*	-2.44
Farm Size (Z_1)	δ_1	-0.0673**	-2.25

Age (Z_2)	δ_2	0.1170**	1.89
Education (Z_3)	δ_3	-0.0944	-0.42
Training (Z_4)	δ_4	-0.1523**	-2.50
Experience (Z_5)	δ_5	-0.3242*	-1.70
Market Distance (Z_6)	δ_6	0.8291	1.05
Log-likelihood Function		**42.27**	

*Note: **, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. Source: Field survey

Table 5 shows that the stochastic frontier production function results for hybrid cotton indicate that several inputs significantly influence productivity. Human labor had a positive and significant effect ($\beta_1 = 0.6774$,

$p<0.05$), suggesting that increased labor use increases output, with a 1 percent rise in labor cost contributing to a 0.68 percent increase in yield. Among the inputs, TSP fertilizer had the largest positive coefficient ($\beta_3 = 0.7819$, $p<0.01$), underscoring the importance of phosphorus in increasing cotton output, whereas gypsum ($\beta_5 = 0.2310$, $p<0.01$) also contributed positively, highlighting the benefits of calcium and sulfur for crop growth. Irrigation ($\beta_6 = 0.0970$, $p<0.01$) had a positive, although smaller, effect, reflecting the significance of an adequate water supply. In contrast, urea had a negative and highly significant coefficient ($\beta_2 = -0.3483$, $p<0.01$), indicating problems of overapplication or inefficient nitrogen use, which reduced output. Other inputs, such as MoP and insecticides, were not statistically significant, suggesting limited or inconsistent impacts on hybrid cotton yields. The inefficiency effects model identified several socioeconomic and management factors influencing farm-level performance. Farm size ($\delta_1 = -0.0673$, $p<0.05$) significantly reduced inefficiency, confirming that larger farms benefit from economies of scale and better resource management. Training ($\delta_4 = -0.1523$, $p<0.05$) also had a negative and significant effect on inefficiency, suggesting that farmers who received training were more efficient, reflecting the effectiveness of extension services. Similarly, experience ($\delta_5 = -0.3242$, $p<0.10$) lowered inefficiency, indicating that experienced farmers manage production more effectively, which is consistent with learning-by-doing. Age ($\delta_2 = 0.1170$, $p<0.05$), however, had a positive effect on inefficiency, suggesting that older farmers were less efficient, possibly due to reluctance to adopt modern practices. Education did not have a significant effect, implying that formal schooling alone may not directly improve cotton production efficiency. Overall, these findings highlight that while labor, fertilizers, and irrigation remain critical to hybrid cotton productivity, efficiency is also shaped by farm size, training, and farmer experience, underscoring the importance of targeted extension support and balanced input management.

Local Cotton Production

Table 6: ML estimates for the Cobb–Douglas stochastic frontier production function - local cotton

Variables	**Parameter**	**Coefficients**	**T-ratio**
Stochastic Frontier:			
Constant (X_0)	β_0	2.93*	1.78
Human Labor (X_1)	β_1	0.0868**	2.22
Urea (X_2)	β_2	-0.1764**	-2.20
TSP (X_3)	β_3	0.2544**	2.30
MoP (X_4)	β_4	-0.1061***	-3.18
Gypsum (X_5)	β_5	-0.2202	-0.70
Irrigation (X_6)	β_6	0.2175*	1.71
Insecticide (X_7)	β_7	-0.2533	-0.58
Inefficiency Model:			
Constant	δ_0	-12.39*	-1.69
Farm Size (Z_1)	δ_1	-0.0154***	-3.47
Age (Z_2)	δ_2	0.5766	0.59
Education (Z_3)	δ_3	0.3070***	2.81
Training (Z_4)	δ_4	0.0601**	2.21

Experience (Z_5)	δ_5	0.1035	0.66
Market Distance (Z_6)	δ_6	0.6807*	1.63
Log-likelihood Function		**20.57**	

*Note: **, ** and * indicate significance at the 1%, 5% and 10% levels, respectively. Source: Field survey

Table 6 shows that the results of the stochastic frontier production function for local cotton production highlight several important relationships between input use and output efficiency. Human labor had a positive and significant effect (β_1 = 0.0868, p<0.05), although the coefficient was smaller than that of hybrid cotton, indicating relatively lower labor productivity. Triple superphosphate (TSP) also had a significant positive influence (β_3 = 0.2544, p<0.05), whereas irrigation (β_6 = 0.2175, p<0.10) contributed positively, suggesting that water availability plays a critical role in local cotton yields. In contrast, urea (β_2 = -0.1764, p<0.05) and Muriate of Potash (MoP) (β_4 = -0.1061, p<0.01) had negative effects, implying that excessive or imbalanced fertilizer application may reduce productivity. The effects of gypsum and insecticides were not significant, reflecting the limited impact on yield variation in this context.

The inefficiency effects model revealed that farm size (δ_1 = -0.0154, p<0.01) significantly reduced inefficiency, confirming that larger farms are more efficient in utilizing resources. Interestingly, education (δ_3 = 0.3070, p<0.01) and training (δ_4 = 0.0601, p<0.05) were associated with greater inefficiency in local cotton production, which contrasts with the hybrid cotton results. This may suggest that training programs are less adapted to local varieties or that farmers are reluctant to apply modern techniques to traditional crops. Other factors, such as age, experience, and market distance, were not statistically significant, although market distance showed a positive tendency, indicating that remoteness may contribute to inefficiency. Overall, the model suggests that improving the input balance and designing tailored extension programs could substantially increase the efficiency of local cotton farming.

Technical Efficiency Distribution

Table 7: Frequency distribution of technical efficiency

Efficiency (%)	Hybrid Variety		Local Variety	
	No. of Farms	Percentage	No. of Farms	Percentage
0-60	2	6.67	6	20.00
61-80	2	6.67	6	20.00
81-90	6	20.00	5	16.67
91-99	20	66.67	13	43.33
Total	30	100.00	30	100.00
Minimum	0.53		0.36	
Maximum	0.99		0.98	
Mean	0.92		0.81	
SD	0.12		0.18	

Source: Field Survey

The analysis of technical efficiency revealed significant differences between hybrid and local cotton farmers in the Kushtia district, as shown in Table 7. The mean technical efficiency for hybrid cotton was 92 percent, with the majority of farmers (66.67 percent) operating at very high efficiency levels between 91 and 99 percent. The efficiency scores ranged from 53 to 99 percent, suggesting that although most farmers are close to the production frontier, there is still potential to increase output by approximately 8 percent through better input use and improved management practices. In contrast, local cotton farmers recorded a lower mean technical efficiency of 81 percent, with only 43.33 percent achieving efficiency levels of 91–99 percent. Their efficiency range was much wider (36–98%), reflecting greater variability in performance. This implies that local variety farmers could increase their output by approximately 19 percent if existing resources were managed more efficiently. The higher mean efficiency and lower standard deviation observed in hybrid cotton (92 percent and

0.12) than in local cotton (81 percent and 0.18) highlight the superior consistency and productivity of hybrid cultivation while also underscoring the scope for improvement among local variety growers.

Production Constraints

Table 8: Cotton production problems and constraints

Type of Problems	No. of Farmers	Percentage	Rank
Long duration of cotton cultivation	55	91.67	1
Low price of cotton	54	90.00	2
Insect attack in cotton field	50	83.33	3
Adverse climate	45	75.00	4
Boll rot attack in cotton field	45	75.00	5
High price of hybrid cotton seed	40	66.67	6
Lack of operating capital	40	66.67	7
Natural calamities	30	50.00	8
Shortage of human labor	30	50.00	9
Lack of scientific knowledge of farming	28	46.67	10
Adulteration of fertilizer, insecticide, and pesticide	25	41.67	11
High price of fertilizers	22	36.67	12
Need high crop management	18	30.00	13
Lack of necessary advice from concerned authority	12	20.00	14

Source: Field Survey

Table 8 shows that the study identified a wide range of constraints affecting cotton production in Kushtia district, with long cultivation durations emerging as the most critical problem, reported by 91.67% of the farmers. Cotton's six-month growing period restricts land availability for other crops and increases household expenses and loan repayment pressure, making it less attractive than short-duration alternatives are. Low market prices were highlighted by 90% of the respondents, as farmers are often forced to sell during harvest when prices are depressed due to inadequate storage and weak bargaining power. Pest incidence was another major challenge, with 83.33% of the farmers reporting severe insect infestations from bollworms and Spodoptera species, which reduce yields and increase production costs, while ineffective insecticide use further resulted in compound losses. Climatic adversities, particularly droughts, floods, and erratic rainfall, were cited by 75% of the farmers, underscoring the role of climate variability as an uncontrollable risk factor. Similarly, 75% of the respondents experienced boll rot, a disease that damages bolls late in the season after significant investment, necessitating costly and additional crop management. High prices of hybrid cotton seeds and other inputs, along with a lack of operating capital, were reported by 66.67% of the farmers, limiting their ability to adopt recommended input packages. Labor shortages during peak seasons (50 percent) and knowledge gaps (46.67 percent) further constrained production efficiency, with many farmers unable to access timely technical advice or training. The adulteration of fertilizers and pesticides, cited by 41.67 percent, also undermined productivity, reflecting weaknesses in input market regulation. High fertilizer prices (36.67 percent), crop management difficulties (30 percent), and inadequate extension services (20 percent) were also noted as significant barriers. Overall, these findings suggest that cotton farmers face a combination of biological, climatic, financial, and institutional constraints, which collectively reduce efficiency and profitability and require comprehensive policy interventions to overcome.

DISCUSSION

The study reveals substantial differences in technical efficiency between hybrid and local cotton varieties, with hybrid farmers achieving 92 percent efficiency compared with 81 percent for local farmers. This efficiency gap highlights the variety-specific management advantages of hybrids, which may stem from more responsive germplasms, stronger extension support, and better targeted input recommendations. The higher efficiency of hybrid cotton also translated into superior profitability (BCR 2.18 vs. 1.65), demonstrating that efficiency gains directly enhance economic performance. Nevertheless, the 19 percent potential output gain for local varieties under current input levels indicates that considerable improvements can be achieved without shifting entirely to hybrids. Farm size significantly reduced inefficiency across both systems, but its effect was more pronounced for local cotton, suggesting economies of scale, better access to resources, and possible indivisibilities in input use or technology adoption. Input use patterns revealed nutrient imbalances, with negative effects of urea and MoP indicating overapplication and poor soil testing practices, whereas positive and significant effects of TSP and irrigation emphasized the importance of balanced fertilization and improved water management technologies. The contrasting effects of education and training across varieties further underscore the need for variety-specific extension strategies. For hybrid cotton, training and experience enhanced efficiency, whereas for local cotton, they appeared to increase inefficiency, possibly reflecting misaligned training content or conflicts with traditional knowledge systems. Moreover, the positive influence of farmer age across both systems suggests that younger farmers are more likely to adopt improved practices, which is consistent with innovation diffusion theory.

In addition to farm-level input and management, production outcomes are constrained by systemic challenges. Market-related issues, such as low cotton prices, inadequate storage facilities, and weak marketing structures, undermine profitability and limit farmers' bargaining power. Climate variability, reported by 75% of the respondents, poses additional risks to productivity, highlighting the urgent need for climate-smart strategies, including drought-tolerant varieties, improved weather forecasting, crop insurance, and adjusted planting schedules. Pest incidence, reported by 83.33 percent of the farmers, underscores gaps in pest control practices, as indicated by insignificant or negative coefficients for insecticide use. This finding points to pesticide resistance, poor application timing, and inadequate pest monitoring, necessitating stronger integrated pest management (IPM) approaches and the incorporation of biological control strategies. These findings call for a comprehensive set of policy interventions. Differentiated extension strategies must be developed to address both hybrid and local systems, with emphasis on strengthening training content, targeting efficiency-improving practices, and enhancing follow-up support. Input market reforms should ensure the quality assurance of seeds and fertilizers, promote balanced fertilization through soil testing, and improve pest management advisory services. The market infrastructure needs to be strengthened through the establishment of storage facilities, price stabilization mechanisms, and contract farming arrangements to secure fair returns for farmers.

In addition to these measures, research priorities should focus on breeding shorter-duration and climate-resilient varieties, optimizing fertilization strategies by soil type, and advancing integrated pest management technologies. Expanding cotton-specific credit programs and developing crop insurance schemes will further help farmers manage risks, while supporting farmer organizations in collective marketing and improving access to capital for input purchases can strengthen resilience. Overall, the discussion highlights that improving technical efficiency and overcoming production constraints in Bangladesh's cotton sector requires not only farm-level improvements but also systemic interventions in extension, markets, research, and risk management.

For further clarification of technical efficiency findings, macroeconomic and policy-level factors of agricultural production are also necessary to be considered, whereas farming-level input-output-conversions may remain outside the farm-level input-output model. In Bangladesh, government policies on input subsidies, credit availability, mechanization support, crop insurance and rural infrastructure investment directly affect cotton farmers' ability to maximize resources. Fertilization and irrigation equipment purchases, along with state bank loans that provide seasonal agricultural loans, are key factors to farmers' ability to make the most of time available. The high price of hybrid seeds also reflects the structure of cotton seed markets whose imports and limited domestic seed production depend heavily on imported grains.

At the global level, changes in international cotton prices and trade policy significantly impact domestic production. The fabric industry in Bangladesh, one of the largest in the world, imports imported cotton, allowing the price shocks in global markets to impact local market incentives. When the prices rise, domestic producers experience downward pressures on farmgate prices, limiting production and investment. On the other hand, high global prices can inspire farmers to increase acreage or to adopt better-quality varieties.

This infrastructure development, encompassing rural roads, storage facilities, and ginning/processing centers, also has an important role to play in cutting postharvest losses and improving farmers access to competitive markets. This low-price problem was found in this study based on limited storage capacity and farmers selling after harvest. This understanding of these larger macroeconomic and policy changes provides a clearer explanation of why technical inefficiency persists despite relatively high input use and training participation.

CONCLUSIONS

This study provides a broad picture of technical efficiency and production challenges of hybrid and local cotton growing in the Kushtia district of Bangladesh. Both authors imply that hybrid cotton farmers have high average technical efficiency of 92% and whereas local cotton farmers have average efficiency of 81%. Plus, these results suggest that a substantial advantage in productivity can be achieved by improving management, although the use of input could not reach an increase in productivity. This largely reflect variation in germplasm performance, input response and management practices that determines the efficiency differences in the two production systems.

Input-specific effects indicate the importance of balanced and rational fertilizer application. Human labor, TSP, gypsum, hybrid cotton irrigation positively correlated output while urea and MoP negatively correlated production with problems of excess applications and imbalance in nutrients. These results suggest the need for more precise nutrient management practices based on soil-test measurements and more specific nutrient guidelines. The inefficiency analyses also revealed that farm size, training, and farming experience significantly reduce inefficiency in hybrid cotton production, while only farm size increases efficiency among local variety growers. These differing effects of training, which benefits hybrid farmers but, at higher levels, leads to greater efficiency in local cotton, suggest that specific extension and capacity-building programs are needed.

Farmers also face complex systemic challenges, including long crop duration, low production prices, high pest incidence, climate change, and limited access to quality inputs and credit. The remaining challenges have implications beyond field level management and require broad institutional and policy responses to improve the overall productive environment for cotton production.

In policy terms, the cotton sector in Bangladesh must be strengthened in an integrated fashion through farm-level efficiency and macroeconomic and institutional support. Prior to developing short-duration and climate resilient varieties, improving extension services with differentiated training strategies, guaranteeing quality and affordable seed and fertilizer markets, and adding storage capacity to discourage distress sales, priority focus includes extending shorter-duration and climate resilient varieties, improving extension services, differentiated training modules, improved seed and fertilizer market quality and inexpensive storage facilities. Pricing stabilization mechanisms, cotton credit programs and crop insurance programs can further increase resilience, encourage investment in cotton cultivation. In national terms, global prices and Bangladesh's considerable dependence on imported cotton, highlight the need to align domestic production strategies with market trends and trade practices.

This study provides empirical evidence in the growing body of technical efficiency studies describing cotton in Bangladesh and proposes strategies for improving productivity and reduced import dependency. Future research needs to examine changes in change over time, cost-efficiency and environmental sustainability measures, and consider value-chain bottlenecks beyond production, processing, marketing, and the potential of Bt cotton. Identifying the efficiency gaps and systemic constraints identified in this study is essential in order to achieve national production goals and minimize the import burden of Tk currently costing the country Tk. 12–15 thousand crore yearly.

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