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Profitability, Resource-Use Efficiency, and Production Constraints of BARI Tomato-14 in the *Haor* Wetlands of Habiganj, Bangladesh

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Abstract

Bangladesh's flood-pulsed *Haor* wetlands compress cultivation into a short winter window, pushing farmers toward short-duration crops, yet the farm-level economics of this adaptation remain undocumented. This study assessed the profitability, resource-use efficiency, and production constraints of BARI Tomato-14 cultivation among 180 farmers in Baniachong Upazila, Habiganj District, using structured interviews from the 2024 season, combining benefit-cost analysis, marginal value product-to-marginal factor cost ratios, a Cobb-Douglas production function, and a Constraints Facing Index validated by confirmatory factor analysis. Cultivation was profitable overall, with a benefit-cost ratio of 3.29. However, net returns varied widely across farms, a pattern consistent with differential flood exposure and land access rather than random error. Land preparation ($\beta = 0.550$) and fertiliser cost ($\beta = 0.396$) were the strongest and most significant drivers of gross return, and both were simultaneously under-utilised relative to their marginal returns, a combination more consistent with binding liquidity constraints than with a lack of technical knowledge. However, this study cannot test that mechanism directly. Lack of extension support, high labour costs, absence of government subsidy, and insect infestation emerged as the most severe constraints, ranked above market-access barriers such as transport cost. BARI Tomato-14 is therefore a viable flood-adaptation strategy whose benefits are presently constrained more by weak institutional support than by the crop's inherent risk; targeted extension, seasonal credit, and certified seedling supply are identified as promising policy levers, with relevance to Bangladesh's *Haor* Master Plan and Sustainable Development Goals 1, 2, and 13.

Keywords: *BARI Tomato-14; Haor wetland; profitability; resource-use efficiency; Cobb-Douglas production function; Constraints Facing Index*

1. Introduction

Bangladesh's northeastern *Haor* basin is a hydrologically singular landscape, a bowl-shaped depression spanning roughly two million hectares across seven districts that lies four to eight meters underwater for nearly eight months of the year and opens to cultivation only during a brief winter window [1,2]. This annual flood pulse compresses an entire cropping cycle into 120-150 days, after which pre-monsoon flash floods can arrive weeks earlier than expected, destroying standing crops overnight [3]. Because the region supplies a fifth of the nation's Boro rice output and ranks among the most climate-exposed agroecosystems, even small shifts in cropping choices or farm-level efficiency can affect household welfare and national food security [2,4].

Confronted with this compressed and unpredictable growing season, *Haor* households are diversifying away from single-season Boro rice toward short-duration, high-value winter vegetables that mature before the flood-risk window opens [4,5]. BARI Tomato-14, a short-duration variety developed for late-winter cultivation, has become one such adaptation option in the Habiganj *Haor*. Climate-smart diversification of this kind is consistent with practices found elsewhere in Bangladesh to raise both productivity and food security [5,7]. Yet, the specific economics of this pathway in the *Haor* remain undocumented. While the profitability and adaptation dynamics of Boro rice in flood-prone wetlands have received sustained attention [3,6], no comparable evidence exists for the short-duration vegetables now being substituted into *Haor* cropping calendars. Without farm-level evidence on returns, input efficiency, and the constraints farmers face, extension agencies cannot judge whether tomato-based diversification is a viable, scalable strategy or merely a stopgap response to flood risk.

This gap also has a direct bearing on policy. The Bangladesh *Haor* and Wetland Development Board's Master Plan for the *Haor* Area explicitly calls for crop diversification and flood-adapted livelihoods. Yet, its implementation has lacked economic evidence specific to crops [8]. Bangladesh's agricultural policy is increasingly framed around SDG 1 (No Poverty), SDG 2 (Zero Hunger), and SDG 13 (Climate Action), each of which depends on identifying practices that are simultaneously profitable and climate-resilient [7].

This study addresses that gap by asking four linked questions: (i) what are the socioeconomic characteristics of BARI Tomato-14 adopters in the Baniachong *Haor*; (ii) is cultivation profitable and are inputs used efficiently; (iii) which socioeconomic and input factors most strongly determine output; and (iv) which constraints most severely limit farmers' ability to sustain or expand this diversification, and how do they rank in severity.

In answering these questions, the study makes three contributions. First, it provides the first farm-level evidence on profitability and resource-use efficiency for a short-duration vegetable grown as a flood-adaptation strategy in the *Haor*, complementing the Boro-rice-centred literature [3,4]. Second, by

statistically validating a Constraints Facing Index through confirmatory factor analysis, it offers a methodologically rigorous ranking of the barriers farmers face rather than a purely descriptive account. Third, by tying its findings to the *Haor* Master Plan and to SDGs 1, 2, and 13, the study is positioned to inform concrete decisions on where to target extension, credit, and input subsidies. Given that the *Haor* supplies a disproportionate share of regional food output from a small, climatically fragile land base, this evidence has implications extending well beyond Habiganj District. The remainder of this paper is organised as follows: the next section describes the study area, sampling, and analytical methods; this is followed by the Results, the Discussion, and finally the Conclusions, which draw out the policy implications and limitations of the study.

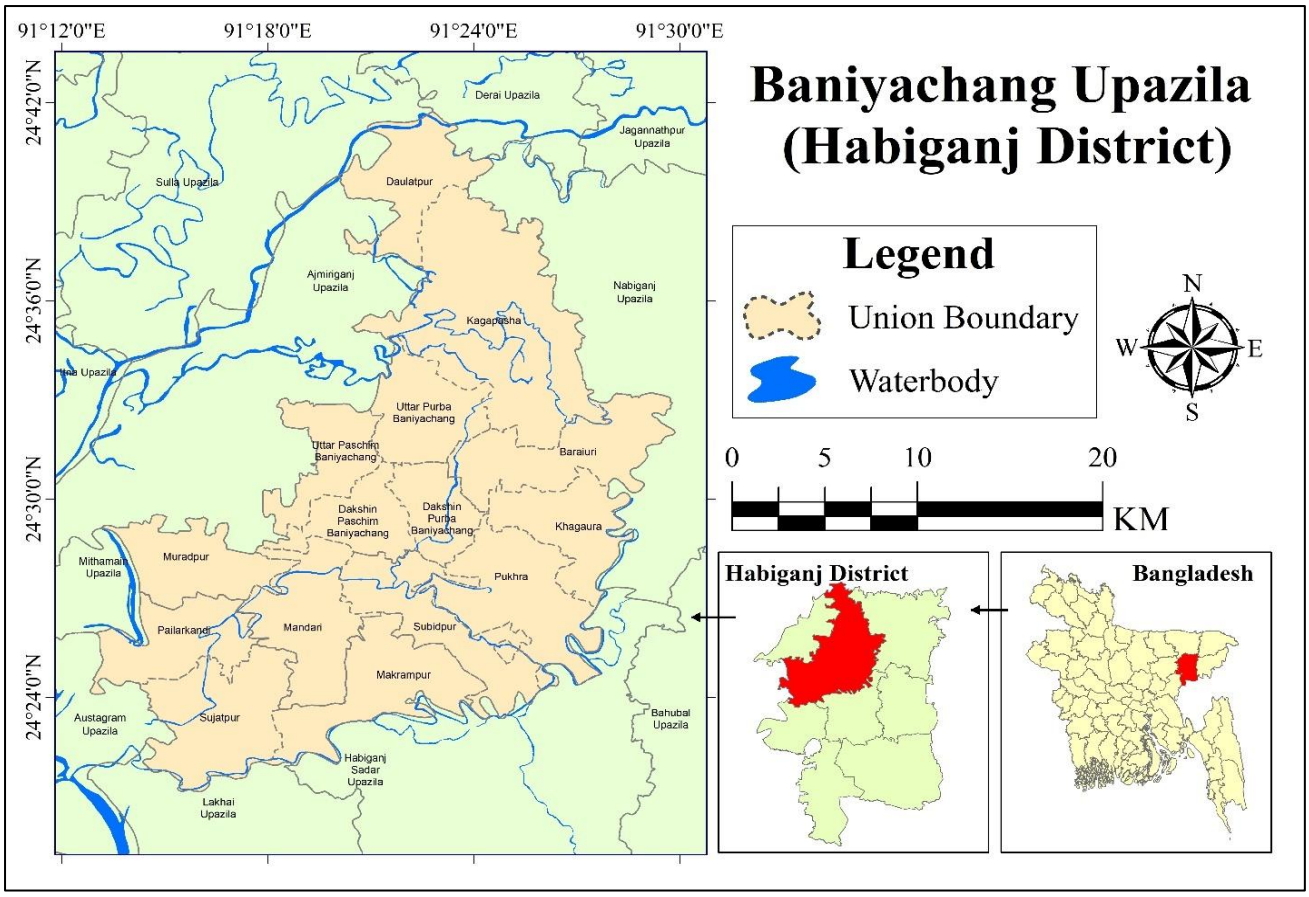
2. Materials and methods

2.1 Conceptual framework

The conceptual framework links the research problem to the analytical steps undertaken to address it [9]. The core premise is that the profitability of BARI Tomato-14 cultivation is a function of costs incurred and returns realised, and that this profitability, together with resource-use efficiency, is shaped by input allocation decisions that, in turn, are constrained by production-limiting factors specific to the *Haor* wetland environment. Cost items considered include seed, labour, land preparation, fertiliser, irrigation, pesticide, and staking/trellising costs, while returns were derived from farm-gate sales value. The study proceeds in four analytical stages: (i) socioeconomic profiling, (ii) profitability and resource-use efficiency analysis, (iii) identification of production determinants using the Cobb-Douglas function, and (iv) construction of a Constraints Facing Index (CFI) to rank the severity of production-limiting factors.

2.2 Study area and sampling procedure

The study was conducted in Baniachong Upazila, a flood-prone *Haor* wetland of Habiganj District, Bangladesh, purposively selected for its concentration of BARI Tomato-14 cultivation during the late-winter (rabi) season (Fig. 1).



105

106 **Fig. 1:** Map of the study area

107 Primary data were collected through face-to-face interviews with tomato growers using a pre-tested,
108 structured questionnaire during the 2024 production season. A sampling frame of 320 growers across
109 the unions of Baniachong was obtained from the agricultural extension office; sample size was
110 determined using Cochran's [10] formula for a finite population at a 95% confidence level and a 5%
111 margin of error:

112 $$n_0 = \frac{Z^2 pq}{e^2} \quad (1)$$

113 $$n = \frac{n_0}{1 + \frac{(n_0 - 1)}{N}} \quad (2)$$

114 where $Z = 1.96$, $p = 0.5$, $q = 1 - p = 0.5$, $e = 0.05$, and $N = 320$. Substituting these values yields $n_0 =$
115 384.16, which, after finite population correction, gives $n \approx 175$, rounded up to 180 farmers to offset
116 non-response. Respondents were selected using proportionate random sampling across unions to
117 ensure geographic representativeness.

2.3 Analytical framework

To achieve the study objectives, both descriptive and econometric techniques were employed. Descriptive statistics, including frequencies, percentages, means, and standard deviations, were used to summarize farmers' socioeconomic characteristics and farming practices using Stata (v. 17).

Farm-level profitability was estimated following the net-return framework of Dillon and Hardaker [11]. Gross return (GR), gross margin (GM), net return (NR), average rate of return (ARR), interest on operating capital (IOC), and the benefit-cost ratio (BCR) were computed as:

$$GR = P \times Q \tag{3}$$

$$GM = TR - TV \tag{4}$$

$$NR = GR - TC \tag{5}$$

$$ARR = \frac{GM}{TC} \times 100 \tag{6}$$

$$IOC = AI \times i \times t \tag{7}$$

$$BCR = \frac{GR}{TC} \tag{8}$$

where P is farm-gate price (Tk./kg), Q is output (kg/ha), TVC and TC are total variable and total cost, AI is average investment (total investment ÷ 2), i is the annual interest rate (12%), and t is the production period (4 months) [12].

Allocative resource use efficiency was assessed using the marginal value product (MVP) to marginal factor cost (MFC) ratio, following Dhawan and Bansal [13]:

$$\frac{MVP_X}{MFC_X} = 1 \tag{9}$$

$$MVP(X_i) = b_i \times \frac{\bar{Y}}{\bar{X}_i} \tag{10}$$

where $\bar{Y}$ is the mean gross return, $\bar{X}_i$ is the mean value of input i, and b_i is the estimated production elasticity of input i. A ratio above 1 indicates underutilization, below 1 overutilization, and near 1 efficient allocation.

A Cobb-Douglas production function identified key factors influencing output, following the two-input specification of Dewett [14], extended to the multi-input case:

$$Q = KL^{a}C^{(1-a)} \tag{11}$$

$$Y = aX_1^{\beta 1} X_2^{\beta 2} \cdots X_n^{\beta n} e^{ui} \tag{12}$$

converted to logarithmic form for OLS estimation:

$$\ln Y = \alpha + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + \beta_6 X_6 + \beta_7 X_7 + \beta_8 X_8 + u_i \quad (13)$$

where Y is gross return (USD/ha); X_1–X_5 represent the costs of labour, land preparation, seed/seedlings, aggregated fertiliser, and irrigation, respectively; X_6, X_7, and X_8 denote education, farming experience, and training exposure, respectively; α is the intercept, β_1–β_8 are the estimated parameters, and u_i is the random error term. Individual fertiliser cost components were aggregated into a single fertiliser cost variable to reduce multicollinearity and improve model stability. Model adequacy was assessed using variance inflation factors (VIF) to detect multicollinearity, the Breusch–Pagan test [15] for heteroskedasticity, the Ramsey RESET test [16] for functional form misspecification, and the Shapiro–Wilk test [17] for normality of the regression residuals. Returns to scale were computed as the sum of the estimated elasticities of the continuous input variables.

Ten constraints retained from questionnaire pre-testing, insect infestation, high input prices, labour scarcity, transportation cost, lack of quality seedlings, low market price, delayed market access, natural calamities, inadequate extension support, and lack of government subsidy, were each rated by respondents on a 5-point Likert scale (1 = Not a problem to 5 = Very severe problem). Each score was normalised to a 0–1 range and averaged across the ten items to give an individual CFI score, multiplied by 100 for interpretability:

$$\text{Normalized Score}_{ij} = \frac{S_{ij} - 1}{4} \quad (14)$$

$$CFI_i = \frac{\sum_{j=1}^{10} (S_{ij} - 1)}{4 \times 10} \quad (15)$$

where Sij represents the Likert response (1–5) of farmer ii for constraint j, the individual CFI score for each farmer was then computed as the average of these normalised scores across all ten constraints:

$$\text{CFI Percentage}_i = CFI_i \times 100 \quad (16)$$

Reliability was assessed using Cronbach's alpha, and a one-factor confirmatory factor analysis (CFA) validated the unidimensional structure of the CFI:

$$CFI = \lambda_1 X_1 + \lambda_2 X_2 + \cdots + \lambda_{10} X_{10} + \varepsilon \quad (17)$$

Constraints were ranked in descending order of their CFA-derived factor loadings (λ) rather than by simple weighted frequency, since loadings indicate each constraint's relative contribution to the overall severity construct, providing a systematic basis for prioritising the most influential production-limiting factors.

3. Results

3.1 Socioeconomic characteristics of the respondents

Table 1 and Table 2 present the socioeconomic, farm, and institutional profiles of the 180 sampled BARI Tomato-14 growers.

Table 1. Socio-demographic, farm, and institutional characteristics of BARI tomato-14 farmers

Variable	Category	Frequency (n)	Percentage (%)
Age	15–64 years	169	93.89
	Above 64 years	11	6.11
Sex	Male	178	98.89
	Female	2	1.11
Marital Status	Single	14	7.78
	Married	165	91.67
	Widow	1	0.56
Education	Illiterate	61	33.89
	Primary	88	48.89
	Secondary	29	16.11
	Higher Secondary	2	1.11
Occupation	Farmer	174	96.67
	Fisherman	2	1.11
	Business	2	1.11
	Others	2	1.11
Farmer Category	Small	102	56.67
	Medium	29	16.11
	Marginal	25	13.89
	Large	24	13.33
Land Ownership	Leased	82	45.56
	Both (Own + Leased)	78	43.33
	Own	20	11.11
Topography	Lowland	138	76.67
	Plain	33	18.33
	Highland	9	5.00
Risk Perception	Taker	80	44.44
	Neutral	54	30.00
	Averse	46	25.56
Membership (Social/Org.)	No	119	66.11
	Yes	61	33.89
Received Training	No	110	61.11
	Yes	70	38.89
Remittance Received	No	164	91.11
	Yes	16	8.89
Government Subsidy	No	150	83.33
	Yes	30	16.67
Internet Access	Yes	97	53.89
	No	83	46.11
Access to Climate Info.	Yes	107	59.44
	No	73	40.56
Experienced Climate Hazard	Yes	145	80.56
	No	35	19.44
Environmental Awareness	Yes	123	68.33
	No	57	31.67

Access to Extension Services	No	115	63.89
	Yes	65	36.11
Labor Availability	Yes	132	73.33
	No	48	26.67

Source: Field survey (2024).

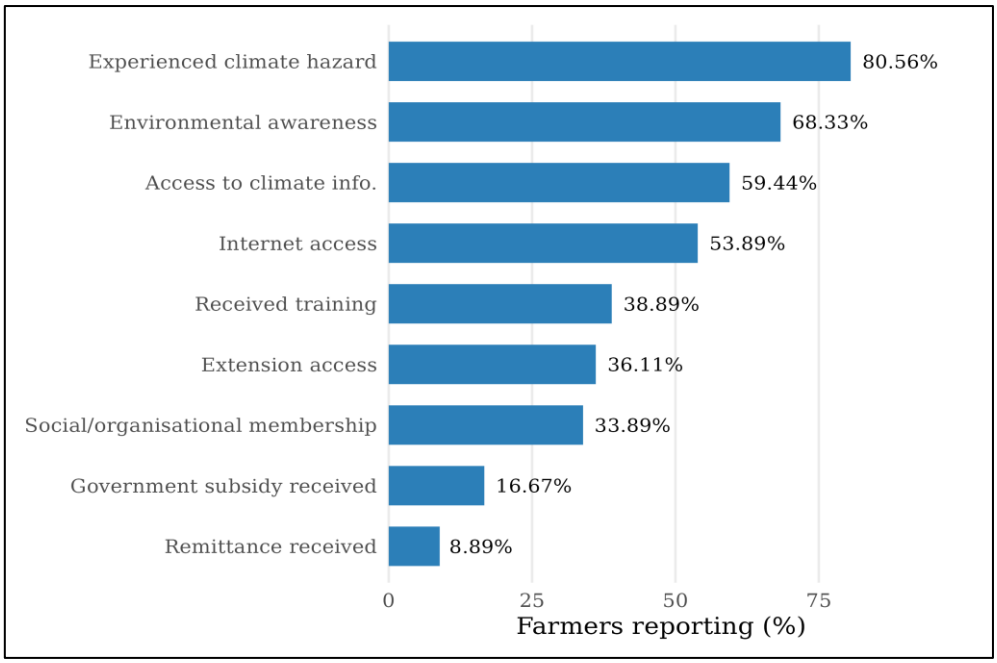
Table 2. Summary statistics of continuous household and farm variables

Variables	Mean	SD	Min	Max
Family Member	6.528	2.455	1.000	15
Dependent Member	4.528	2.089	1.000	13
Farming Experience	13.433	10.672	1.000	60
Distance of the market from the farm	3.132	2.17	0.300	12
Distance of the market from the household	2.197	1.225	0.400	07

Source: Field survey (2024).

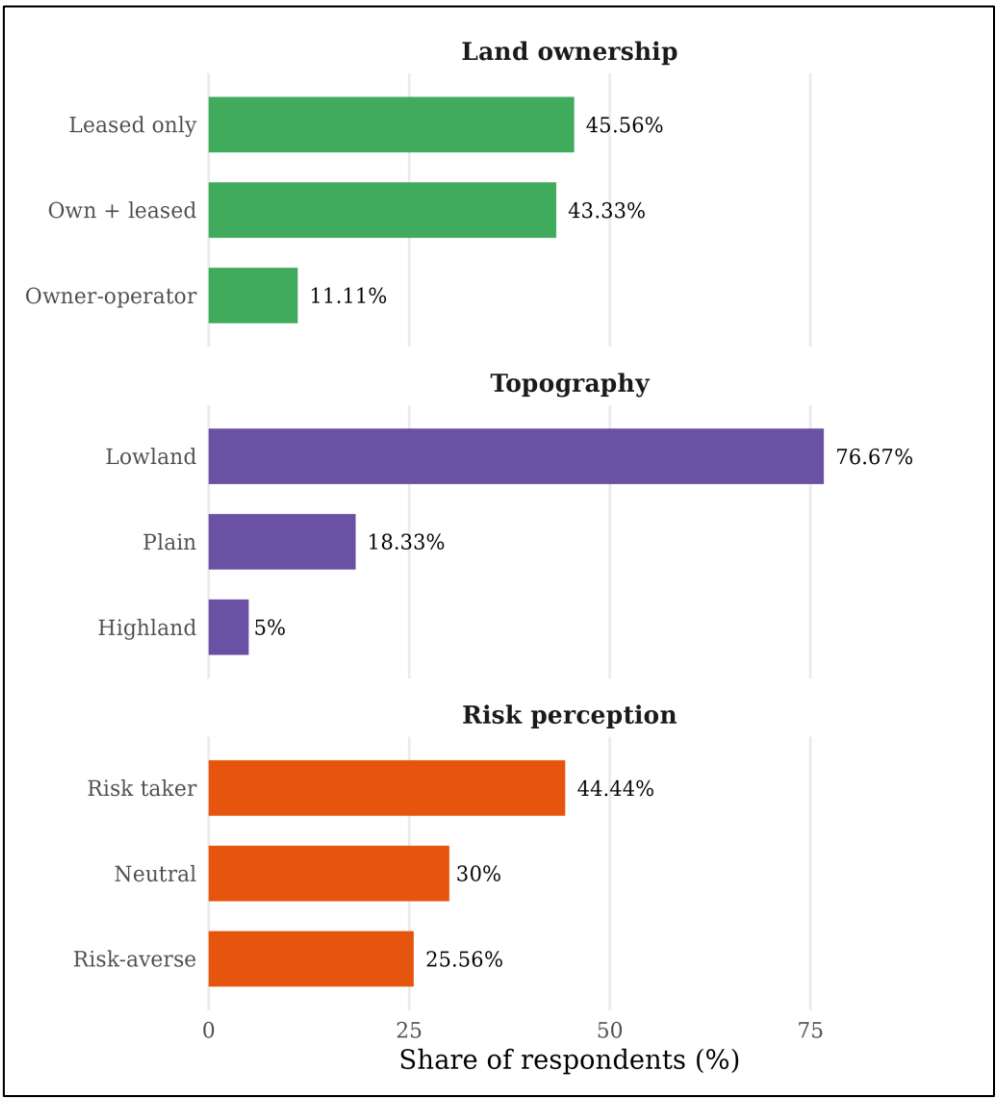
Table 1 shows that BARI Tomato-14 cultivation in Baniachong is undertaken by a demographically active but institutionally underserved farming population. Approximately 94% of respondents belonged to the economically active age group, and farming was the principal occupation for 96.67% of the sample, indicating that tomato cultivation is a full-time livelihood rather than a supplementary activity. The sample was 98.89% male, a reflection of the household-head interview design rather than necessarily of the totality of labour actually invested in tomato cultivation (see Section 4.1). A combined 82.78% of farmers had no more than a primary education, of whom 33.89% were illiterate, underscoring the limited formal human-capital base from which extension messaging must work.

As Fig. 3 illustrates, land access was dominated by leasing: 45.56% of respondents cultivated exclusively leased land, and a further 43.33% combined owned and leased parcels, leaving only 11.11% as full owner-operators; lowland topography, the micro-terrain most exposed to residual flood risk, accounted for 76.67% of holdings. Farmers were fairly evenly split in risk orientation, with 44.44% self-identifying as risk takers, 30.00% as neutral, and 25.56% as risk-averse, a distribution consistent with a population making an active choice to grow a flood-timed cash crop rather than defaulting into it. As Fig. 2 shows, institutional support was limited relative to this exposure: only 36.11% of farmers had received extension contact, 38.89% had received training, and 16.67% had received a government subsidy, even though 80.56% reported having personally experienced a climate-related hazard and 68.33% reported general environmental awareness. Social or organisational membership (33.89%) and remittance receipt (8.89%) were similarly low, suggesting limited access to either collective or migration-based buffers against production risk. Just over half of farmers (53.89%) reported internet access, a channel of institutional reach discussed further in Section 4.1.



203

204 **Fig. 2:** Institutional access and climate-hazard exposure among sampled farmers (n = 180).



205

206 **Fig. 3:** Land tenure, topography, and risk orientation of sampled farmers.

Table 2 complements this profile. Households averaged 6.5 members, of whom 4.5 were classified as dependents, leaving roughly two members per household in economically active roles, a substantial dependency burden relative to household labour supply. Mean farming experience was 13.4 years, but the wide standard deviation (10.7 years) and range (1–60 years) indicate a cohort mixing long-established growers with recent entrants, consistent with BARI Tomato-14 being a comparatively recently disseminated variety. Markets were, on average, close to both farm (3.1 km) and household (2.2 km), suggesting that market distance is unlikely to be the binding constraint on commercialisation, a point returned to in the discussion of the Constraints Facing Index (Section 4.8).

3.2 Profitability of BARI tomato-14 production in the study area

Table 3. Profitability indicators of BARI tomato-14 production (USD/ha, 2024 season)

Variable	Mean	SD	Minimum	Maximum
Yield (kg/ha)	17,684.36	23,715.77	500	133,000
Selling price (USD/kg)	0.49	0.10	0.34	0.68
Total variable cost (USD/ha)	2,008.76	2,692.29	86.75	15,186.25
Total fixed cost (USD/ha)	357.47	253.35	136.75	1,504.27
Total cost (USD/ha)	2,366.23	2,936.73	243.78	16,421.29
Gross return (USD/ha)	8,700.38	12,023.68	235.04	73,380.34
Net return (USD/ha)	6,344.94	9,289.26	-26.92	60,242.48
Benefit-cost ratio	3.29	1.13	0.90	8.92

Note. Monetary values were converted using USD 1 = BDT 117.00 (2024 average exchange rate).
Source: Field survey (2024).

Table 3 shows that BARI Tomato-14 cultivation was profitable for the sample as a whole, though outcomes were far from uniform. Mean yield was 17,684.36 kg/ha, but the standard deviation (23,715.77 kg/ha) exceeded the mean, indicating that yield outcomes were highly heterogeneous rather than clustered around a typical value. The mean farm-gate price was USD 0.49/kg and varied comparatively little (SD = USD 0.10/kg; range USD 0.34–0.68/kg), showing that price risk was a secondary source of variability relative to yield risk in this sample. Total variable cost (USD 2,008.76/ha) accounted for the large majority of total cost (USD 2,366.23/ha), with fixed cost contributing a smaller and far less variable USD 357.47/ha.

Combining these components, the mean gross return was USD 8,700.38/ha against a mean total cost of USD 2,366.23/ha, yielding a mean net return of USD 6,344.94/ha and a benefit-cost ratio (BCR) of 3.29 (Fig. 4); that is, each dollar invested in cultivation returned USD 3.29 in gross revenue on average. As with yield, however, the spread around this average was substantial: as Fig. 5 illustrates, net return ranged from USD -26.92/ha to USD 60,242.48/ha, with a standard deviation (USD 9,289.26/ha) that exceeded the mean itself, and the BCR ranged from 0.90, a small loss-making minority, to 8.92, highly

profitable operations. This combination of a healthy average return and extreme dispersion is interpreted substantively, rather than as statistical noise, in Section 4.3.

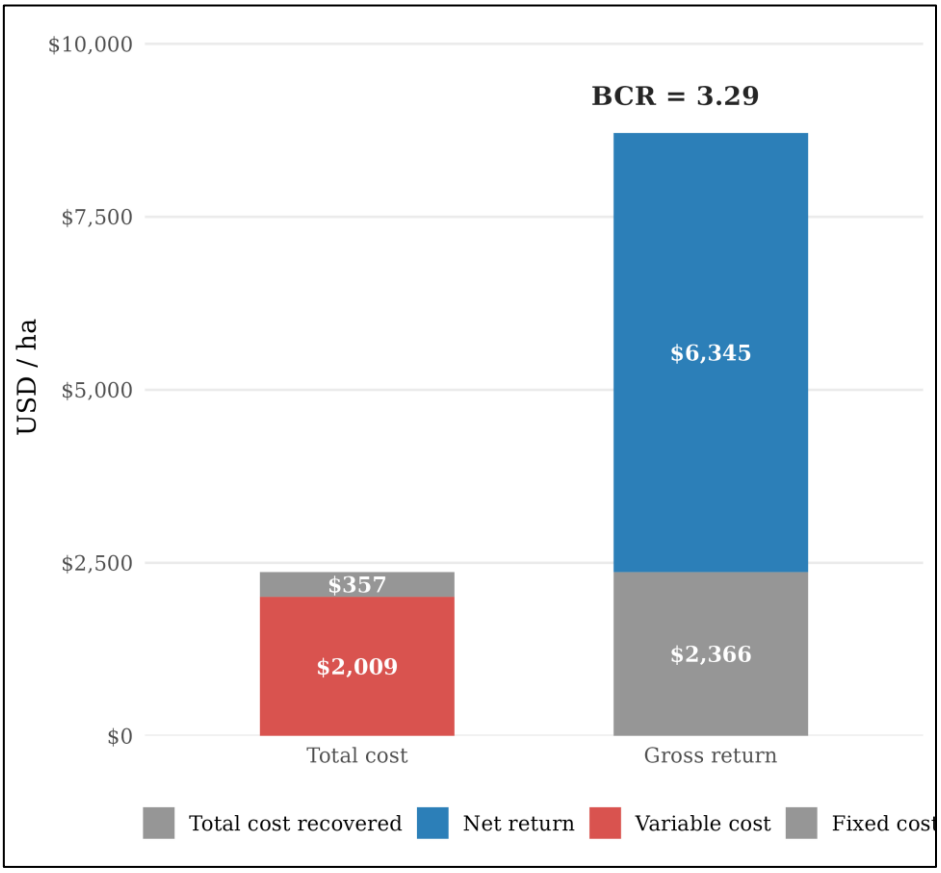


Fig. 4: Cost and return structure of BARI Tomato-14 cultivation (USD/ha, 2024 season).

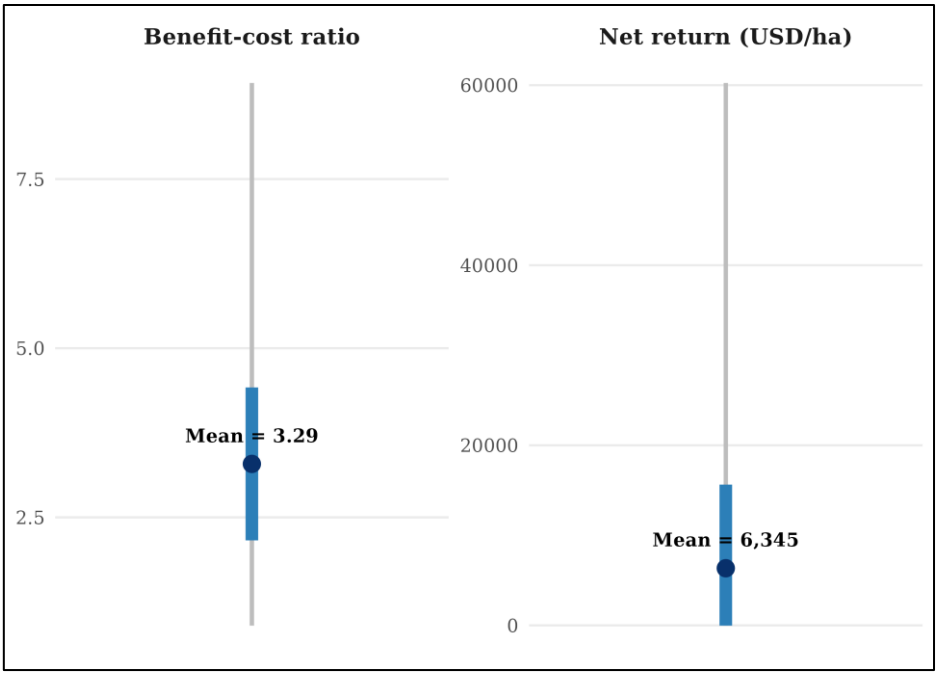


Fig. 5: Dispersion in benefit-cost ratio and net return across sampled farms.

Table 4. Cobb–Douglas production function estimates for gross return

Variable	Coefficient	SE	t	p
ln(Labor cost)	0.048	0.068	0.71	0.476
ln(Land preparation cost)	0.550***	0.080	6.84	<0.001
ln(Seedling cost)	-0.066	0.085	-0.77	0.443
ln(Fertilizer cost)	0.396***	0.099	3.98	<0.001
ln(Irrigation cost)	0.066*	0.036	1.86	0.064
Education	0.026	0.029	0.88	0.381
Farming experience	0.001	0.002	0.56	0.577
Received training	0.034	0.039	0.89	0.374
Constant	4.416***	0.330	13.40	<0.001

Note. Dependent variable: ln(Gross return). * $p < .10$, ** $p < .05$, *** $p < .01$. $N = 180$; $R^2 = 0.957$; Adjusted $R^2 = 0.955$; $F = 477.54$ ($p < .001$).

Source: Field survey (2024).

Table 4 reports the Cobb–Douglas estimates for gross return. Land preparation cost was, by a wide margin, the strongest driver of output (Fig. 6; $\beta = 0.550$, $p < .001$): holding other inputs constant, a 10% increase in land preparation spending was associated with an approximately 5.5% increase in gross return. Fertiliser cost was the second-strongest and also highly significant driver ($\beta = 0.396$, $p < .001$), while irrigation cost was positive but only weakly significant at the 10% level ($\beta = 0.066$, $p = .064$). Together, these three inputs accounted for essentially all of the output elasticity attributable to variable production costs. Labour cost ($\beta = 0.048$, $p = .476$) and seedling cost ($\beta = -0.066$, $p = .443$) were statistically indistinguishable from zero, as were the three human-capital variables: education ($\beta = 0.026$, $p = .381$), farming experience ($\beta = 0.001$, $p = .577$), and training exposure ($\beta = 0.034$, $p = .374$). Model fit was exceptionally strong for a cross-sectional farm-survey specification, explaining 95.7% of the variance in gross return ($R^2 = 0.957$; adjusted $R^2 = 0.955$; $F = 477.54$, $p < .001$).

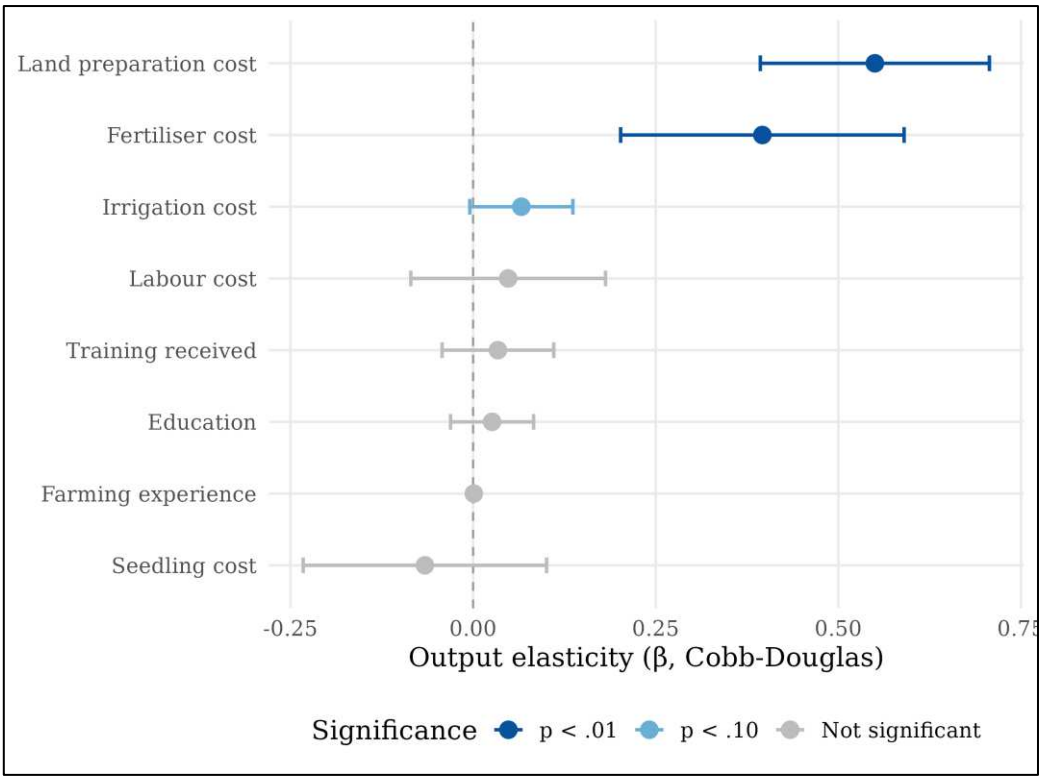


Fig. 6: Cobb-Douglas production function elasticities with 95% confidence intervals.

Table 5. Diagnostic tests for the Cobb–Douglas production function

Diagnostic	Statistic	Interpretation
Mean VIF	14.92	Moderate multicollinearity
Breusch–Pagan test	p = 0.998	No heteroskedasticity
Ramsey RESET	p = 0.364	No specification error
Shapiro–Wilk	p = 0.881	Residuals normally distributed
Returns to scale	0.995	Approximately constant returns to scale

Source: Field survey (2024).

Table 5 summarises the diagnostic tests underpinning the Cobb–Douglas specification. The mean variance inflation factor (14.92) indicated moderate multicollinearity among the input-cost regressors, an expected feature of a model in which several cost categories move together across farms of different scales; this is addressed directly in Section 4.6. The Breusch–Pagan test found no evidence of heteroskedasticity (p = 0.998), the Ramsey RESET test found no evidence of functional-form misspecification (p = 0.364), and the Shapiro–Wilk test confirmed that the regression residuals did not depart from normality (p = 0.881); together these tests indicate that the ordinary least squares standard errors and significance tests reported in Table 4 are reliable despite the elevated VIF. The sum of the elasticities of the five continuous cost inputs was 0.995, indicating returns to scale statistically indistinguishable from constant: proportionate increases in all variable inputs together would be expected to generate an approximately proportionate increase in gross return, with no evidence of increasing or decreasing returns to overall input scale in this sample.

3.3 Resource-use efficiency of major production inputs

Table 6. Resource-use efficiency (MVP/MFC ratios) of major production inputs

Input	Elasticity	MVP	MFC	MVP/MFC	Decision
Labor	0.048	1.20	1.00	1.20	Under-utilized
Land preparation	0.550	68.72	1.00	68.72	Under-utilized
Seedling	-0.066	-0.44	1.00	-0.44	Over-utilized
Fertilizer	0.396	14.57	1.00	14.57	Under-utilized
Irrigation	0.066	12.49	1.00	12.49	Under-utilized

Note. An MVP/MFC ratio >1 indicates underutilization, <1 indicates over-Utilisation, and ≈1 indicates efficient resource use. Source: Field survey (2024).

Table 6 and Fig. 7 translate the production-function elasticities into resource-use efficiency ratios (MVP/MFC). Labour use was close to, though still above, the efficient benchmark (ratio = 1.20), suggesting only mild under-utilisation. Fertiliser (14.57) and irrigation (12.49) were both substantially under-utilised, implying that farmers could profitably expand spending on these inputs several-fold before reaching the point of diminishing marginal returns. However, the irrigation ratio rests on an elasticity that was only weakly significant at the 10% level (Table 4) and should therefore be interpreted more cautiously than the fertiliser and land preparation figures. Land preparation showed by far the largest disparity (ratio = 68.72): at current expenditure levels, the marginal value product of an additional dollar spent on land preparation was worth roughly 69 times its marginal factor cost, an efficiency gaps an order of magnitude larger than for any other input. Seedling use, consistent with its negative output elasticity, returned a negative MVP/MFC ratio (-0.44), formally classified as over-utilisation. However, this figure is best interpreted together with the production-function evidence discussed in Section 4.5 rather than as a literal recommendation to reduce seedling purchases.

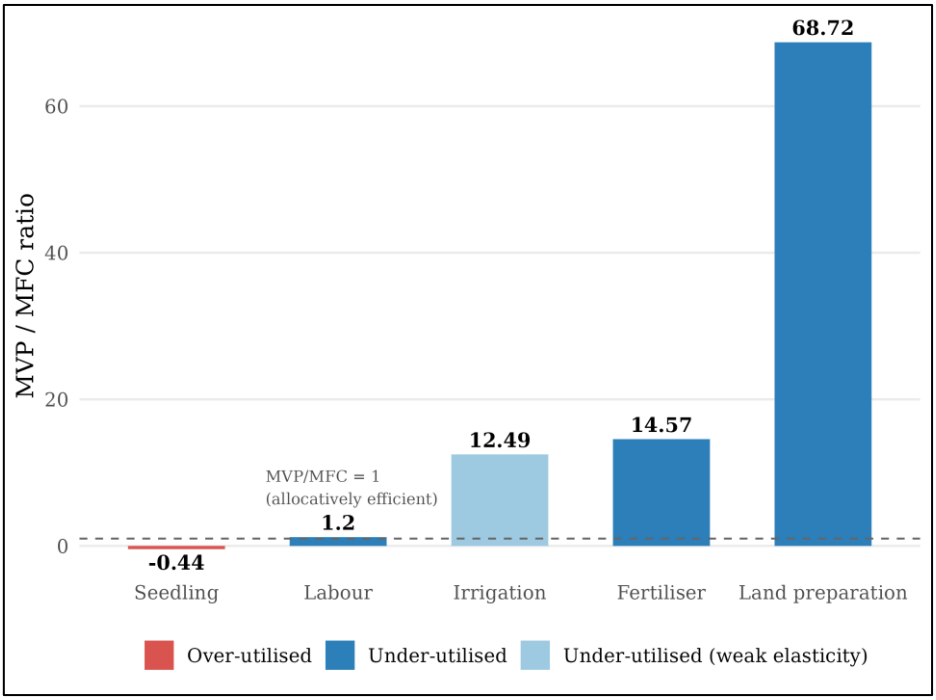


Fig. 7: Resource-use efficiency (MVP/MFC) ratios of major production inputs.

290 **3.4 Major constraints affecting BARI tomato-14 production**

291 **Table 7. Confirmatory factor analysis of the constraints facing index (CFI): model fit, factor**
292 **loadings, and constraint rankings**

293 **Panel A. Model fit statistics**

Metric	Value
Chi-square (χ^2)	124.56
Degrees of freedom (df)	35
Chi-square/df ratio	3.56
RMSEA	0.092
CFI (Comparative Fit Index)	0.902
TLI (Tucker-Lewis Index)	0.878
SRMR	0.068
Cronbach's Alpha (α)	0.821

294 **Panel B. Factor loadings with significance tests**

Constraints	Loading (λ)	Standard Error	Z-value	p-value	Significance
Lack of agricultural extension support	0.77	0.06	12.83	<0.001	***
Unavailability and high cost of labour	0.74	0.06	12.33	<0.001	***
Lack of government subsidy	0.72	0.06	12.00	<0.001	***
Insect infestation	0.71	0.06	11.83	<0.001	***
High price of insecticides	0.68	0.07	9.71	<0.001	***
Natural calamities	0.65	0.07	9.29	<0.001	***
Low market price of tomatoes	0.62	0.07	8.86	<0.001	***
Inability to sell products on time	0.59	0.08	7.38	<0.001	***
High transportation costs	0.55	0.08	6.88	<0.001	***
Lack of quality seeds/seedlings	0.48	0.09	5.33	<0.001	***

295 *Note: *** $p < 0.001$ Source: Field survey (2024).*

Panel C. Ranking of Constraints by Severity (Based on Factor Loadings and Mean Scores)

Rank	Constraint	Factor Loading (λ)	Mean Score	Std. Deviation	Interpretation
1	Lack of agricultural extension support	0.77	2.76	1.27	Most severe constraint
2	Unavailability and high cost of labour	0.74	2.85	1.23	Second most severe
3	Lack of government subsidy	0.72	2.92	1.22	Third most severe
4	Insect infestation	0.71	2.78	1.19	Fourth most severe
5	High price of insecticides	0.68	3.41	1.17	Fifth most severe
6	Natural calamities	0.65	2.18	1.15	Sixth most severe
7	Low market price of tomatoes	0.62	1.87	1.10	Seventh most severe
8	Inability to sell products on time	0.59	1.84	1.09	Eighth most severe
9	High transportation costs	0.55	1.68	1.06	Ninth most severe
10	Lack of quality seeds/seedlings	0.48	1.35	0.99	Least severe constraint

Panel D. Construct Reliability and Validity Summary

Construct	No. of Items	Cronbach's α	CR (Composite Reliability)	AVE (Average Variance Extracted)
Tomato Farming Constraints Index (CFI)	10	0.821	0.835	0.424

Table 7 presents the one-factor confirmatory factor analysis (CFA) underlying the Constraints Facing Index. Model fit was acceptable overall: the χ^2/df ratio (3.56) and the Comparative Fit Index (CFI = 0.902), Tucker-Lewis Index (TLI = 0.878), and Standardised Root Mean Square Residual (SRMR = 0.068) all met or approached conventional thresholds for adequate fit, though RMSEA (0.092) was somewhat above the conventional 0.08 cut-off, a point taken up in Section 4.8. All ten factor loadings were statistically significant ($p < .001$) and ranged from 0.48 to 0.77, confirming that each of the ten constraints contributes meaningfully to a single underlying severity construct. By factor loading (Fig. 8), the four most severe constraints were lack of agricultural extension support ($\lambda = 0.77$), unavailability and high cost of labour ($\lambda = 0.74$), lack of government subsidy ($\lambda = 0.72$), and insect infestation ($\lambda = 0.71$); lack of quality seeds/seedlings loaded lowest ($\lambda = 0.48$), despite the seedling-quality concerns already implied by the production-function results in Table 4. Ranking constraints instead by raw mean Likert severity produced a materially different ordering: high price of insecticides carried the highest mean score (M = 3.41) but ranked only fifth by factor loading, while lack of extension support carried a comparatively moderate mean (M = 2.76) yet ranked first by loading; this loading-versus-mean divergence is interpreted in Section 4.8. Internal consistency of the ten-item scale was good (Cronbach's $\alpha = 0.821$; composite reliability = 0.835), while average variance extracted

(AVE = 0.424) fell below the conventional 0.50 threshold for strong convergent validity, indicating that the CFI functions as a reliable ordinal ranking instrument even though individual items retain substantial item-specific variance.

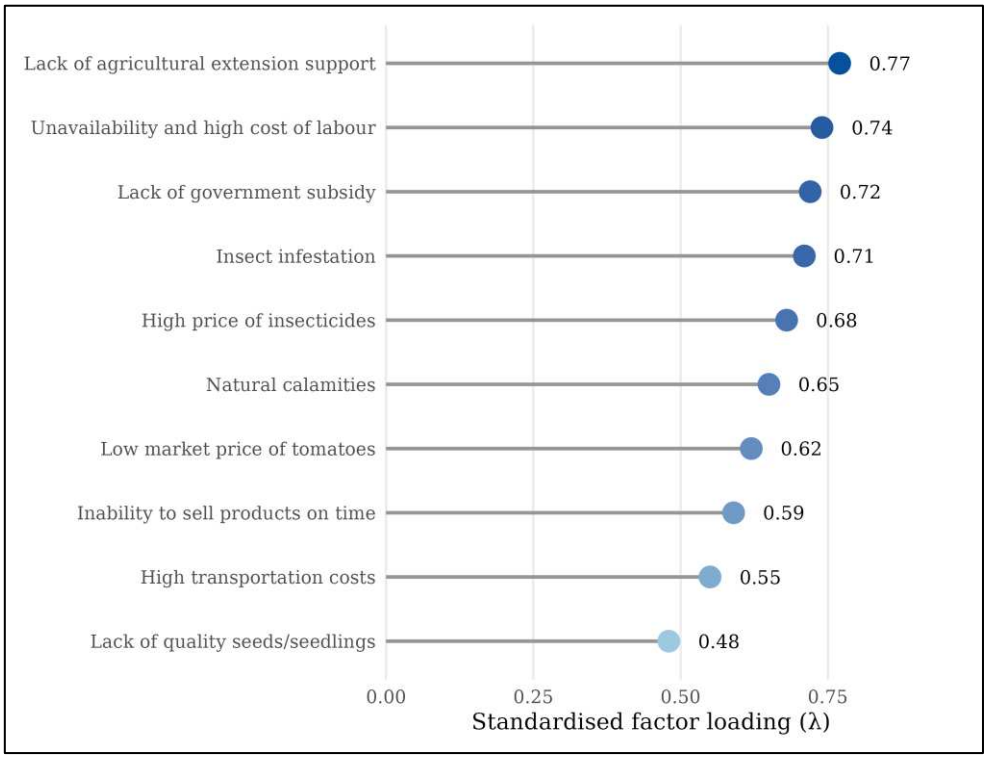


Fig. 8: Factor loadings of production constraints from the confirmatory factor analysis.

4. Discussion

4.1 Sample profile, land tenure, and institutional exposure

The near-total male composition of the sample (98.89%) reflects the study's household-head interview design rather than the totality of labour inputs into tomato production. Bangladeshi women's contribution to vegetable cultivation is frequently concentrated in unpaid, in-homestead, and post-harvest tasks that are rarely captured when a single household head is interviewed as "the farmer"; recent qualitative evidence from Bangladesh's own vegetable-cultivation transition documents this labour as systematically underpaid and undervalued even as it becomes increasingly essential to household cash income [35]. The sample, therefore, likely under-represents women's actual labour input into BARI Tomato-14 cultivation, a limitation acknowledged directly in Section 7.

The predominance of leased land (45.56% exclusively leased, 43.33% mixed) matters directly for the efficiency results discussed in Section 4.7, because farmers cultivating leased *Haor* land typically hold short, single-season contracts that blunt the incentive to invest in land-improving inputs. Cross-country evidence on land tenure consistently finds that insecure or short-duration land rights are associated with lower investment in land improvement and reduced input intensity, even where the profitability

of such investment is unambiguous [36]. This mechanism is consistent with, though not directly tested by, the under-utilisation of land preparation and fertiliser documented in Section 4.7.

The combination of high climate-hazard exposure (80.56%) and low institutional coverage, extension (36.11%), training (38.89%), and subsidy (16.67%) foreshadows the severity rankings from the Constraints Facing Index discussed in Section 4.8. That just over half of farmers (53.89%) already have internet access suggests that digital extension channels, shown elsewhere in South Asia to raise smallholder input intensity and crop income [18], could reach a majority of this population even though conventional in-person extension coverage remains thin.

4.2 Profitability of BARI Tomato-14 relative to competing Rabi enterprises

The mean BCR of 3.29 sits toward the upper end of the range reported for vegetable and cash-crop enterprises elsewhere in Bangladesh: hybrid summer tomato has returned a full-cost BCR near 4.2 [19], tomato subject to price and production risk a BCR of roughly 2.3 [20], and maize, a competing rabi diversification option, a substantially lower BCR of 1.4–1.7 [21]. Positioned against this comparator set, BARI Tomato-14 performs competitively with, though not exceptionally above, the best-performing vegetable enterprises documented in the literature, while clearly outperforming maize as a rabi diversification choice. This relatively strong return is consistent with BARI Tomato-14's short duration and premium late-winter price window, which together reduce flood-risk exposure per unit of expected revenue relative to slower-maturing alternatives. The comparatively narrow dispersion in farm-gate price (Table 3) further suggests that this profitability advantage is driven primarily by yield and cost management rather than by favourable or volatile output prices.

4.3 Flood-pulsed heterogeneity in farm-level returns

The extreme dispersion in net return, whose standard deviation exceeds its mean, is not an estimation artefact but a meaningful feature of production in a flood-pulsed wetland. Farmers on lowland, plain, and highland micro-topographies (Table 1) face materially different residual flood risk and effective growing-season length even within a single *rabi* season so that that output can differ by an order of magnitude across a few hundred metres of elevation. This mirrors flood-prone rice systems in the same *Haor* basin, where profitability hinges heavily on micro-level flood timing rather than on management quality alone [3,6]. The small negative-return tail (minimum BCR = 0.90) is therefore best read not as evidence that tomato cultivation is inherently unreliable, but as a signal that the most flood-exposed growers absorb a downside risk that the average farmer avoids, with direct implications for targeting index-based insurance toward the plots most exposed to residual flood risk, a point developed further in the Conclusions.

4.4 Land preparation and fertiliser as the dominant drivers of gross return

The dominance of land preparation and fertiliser cost as productivity drivers is consistent with the *Haor*'s specific agronomic constraint: because the growing window opens only after floodwaters recede and closes before the next flash flood arrives, timely and thorough land preparation is what allows a farmer actually to capture the short, safe planting period, so incremental spending on this input translates directly into usable growing days and, through that channel, into yield. The magnitude of the land preparation elasticity ($\beta = 0.550$) relative to fertiliser ($\beta = 0.396$) suggests that, in this cropping system, timing and access to land preparation services are at least as productivity-critical as the biochemical input itself, a pattern distinctive to short-window, flood-recession agriculture rather than typical of vegetable production in general. This finding mirrors other Bangladeshi vegetable and maize studies, in which land preparation and fertiliser-related inputs have consistently emerged as the most productive cost categories. In contrast, pesticide and labour costs have often shown weak or insignificant coefficients once other inputs are controlled for [21].

4.5 The seedling-cost anomaly

The negative, though statistically insignificant, coefficient on seedling cost ($\beta = -0.066$, $p = .443$) is the finding most likely to be read as anomalous and merits direct interpretation. A negative point estimate does not imply that seedlings are harmful to yield; because the coefficient is not distinguishable from zero, the more defensible reading is that seedling cost in this sample is a poor proxy for seedling quality, and farmers who pay more are not necessarily obtaining higher-germinating or disease-free stock. Consistent with this, the same farmers independently identified "lack of quality seedlings" as a production constraint (Table 7), even though it loaded lowest on the CFA ($\lambda = 0.48$; Section 4.8). The production-function and constraints-index results are therefore mutually reinforcing rather than contradictory at face value: farmers report that seedling quality, not price, is the binding issue, a pattern common in smallholder seed markets where information asymmetry between suppliers and buyers is severe [22], pointing toward certified-seedling supply chains, rather than price subsidies, as the more appropriate policy lever.

4.6 Human capital, model diagnostics, and their limits

The lack of significance for education, farming experience, and training runs counter to a common prior in the technology-adoption literature, in which human-capital variables typically predict output positively. Two explanations are plausible and not mutually exclusive. First, BARI Tomato-14 is a recently disseminated variety grown by a cohort that, per Table 2, includes many first- or second-season growers (farming experience: mean 13.4 years, SD 10.7 years), so accumulated tacit knowledge specific to this crop may not yet have had time to translate into higher output. Second, because training coverage was low (38.89%) and unevenly distributed, the regression may lack sufficient variation in a

high-quality training signal, particularly if the training received was generic rather than tailored to flood-adapted vegetable systems [23,24]. Both explanations point toward institutional extension and structured, crop-specific training, rather than general experience alone, as the more scalable channel for closing the observed productivity gap.

Regarding the diagnostics reported in Table 5, a mean VIF above 10 is sometimes treated as an automatic disqualifying threshold for a regression model. Still, this rule of thumb is context-dependent and does not by itself invalidate coefficient estimates [25,26]. The present model remains informative because the coefficients of greatest substantive interest, land preparation and fertiliser cost, stay individually significant at conventional levels, and the specification otherwise satisfies the Breusch–Pagan, Ramsey RESET, and Shapiro–Wilk diagnostics without qualification. The elevated mean VIF most plausibly reflects farm-scale effects common to survey-based production functions: land preparation, fertiliser, and irrigation expenditure would all be expected to move together across larger versus smaller operations, inflating standard errors without necessarily biasing the coefficients themselves. This inflates uncertainty around the precise magnitude of each elasticity without overturning their sign or relative ranking, but it does mean the point estimates, particularly the very large land-preparation elasticity discussed in Section 4.7, are best read as indicative rather than precise; a per-variable VIF decomposition or pairwise input-cost correlation check would be a useful robustness addition in any follow-up analysis of this dataset.

4.7 Resource-use efficiency and the liquidity-constraint hypothesis

The very large under-utilisation ratio for land preparation (MVP/MFC = 68.72) is directly consistent with the production-function findings: because this input carries by far the largest elasticity, even a small increase in spending would, at current prices, generate returns well in excess of marginal cost; given the elevated VIF discussed in Section 4.6, however, this magnitude is best read as indicative of a large efficiency gap rather than as a precise multiple. A liquidity or cash-flow constraint is the explanation most consistent with this pattern, since a purely knowledge-based account would not obviously predict systematic under-investment in an input whose profitability is this unambiguous, making a lack of technical know-how a correspondingly less plausible explanation. It should be stressed, however, that the questionnaire did not include a direct measure of credit access or loan denial, so this remains the best-supported inference from the available evidence rather than a directly tested causal claim; formally testing it, for example, by comparing input intensity between farmers with and without credit access, is identified as a priority for future work in Section 7. The interpretation is nonetheless consistent with broader evidence that limited access to timely, affordable credit persistently constrains optimal input allocation among smallholders, who under-invest in profitable inputs not because expected returns are unclear but because working capital is unavailable precisely

when needed, the pre-planting window immediately after floodwaters recede. The prevalence of leased land tenure discussed in Section 4.1 plausibly compounds this constraint, since lessees on short, single-season contracts are less likely to hold the collateral or credit history that formal lenders typically require [36].

The over-utilisation of seedlings (MVP/MFC = -0.44), read together with the negative production-function coefficient discussed in Section 4.5, again points toward improving quality per unit of seedling expenditure rather than reducing seedling use outright. The under-utilisation of fertiliser (14.57) and irrigation (12.49), while smaller in magnitude than for land preparation, is consistent with reports that Bangladeshi vegetable farmers frequently apply these inputs below agronomically recommended levels, often for the same liquidity reasons, or owing to uncertainty about optimal timing in the absence of extension contact.

4.8 Interpreting the Constraints Facing Index: severity, prevalence, and fit

The apparent tension between the CFA ranking, in which seedling quality ranks least severe, and the econometric evidence on seedlings discussed in Section 4.5 is informative rather than contradictory: a factor loading measures how strongly a constraint covaries with the shared latent construct of overall production difficulty across the sample, not how severely that specific problem is experienced in isolation. Seedling quality may be a serious problem for a subset of farmers without rising and falling together with the other nine problems across the full sample, which is precisely what a lower loading signal indicates. The CFI ranking and the production-function findings should therefore be read as complementary rather than competing evidence.

A second notable pattern, illustrated in Fig. 9, is the divergence between raw mean severity and factor-loading rankings: high price of insecticides carries the highest mean severity (M = 3.41) yet ranks only fifth by loading ($\lambda = 0.68$). In contrast, lack of extension support carries a more modest mean (M = 2.76) yet ranks first. This is a familiar feature of Likert-based severity indices: a constraint rated severe by nearly every respondent, high mean, low variance, discriminates weakly between more- and less-affected farmers, whereas one rated more moderately on average but varying more systematically with farmers' broader difficulty profile loads more strongly on the latent factor [27]. In substantive terms, insecticide prices appear to be a near-universal cost pressure facing essentially all growers [22,28]. Unequal access to extension, in contrast, is what most sharply distinguishes farmers who are coping well from those who are not, making it the more useful target for triage under limited implementation capacity.

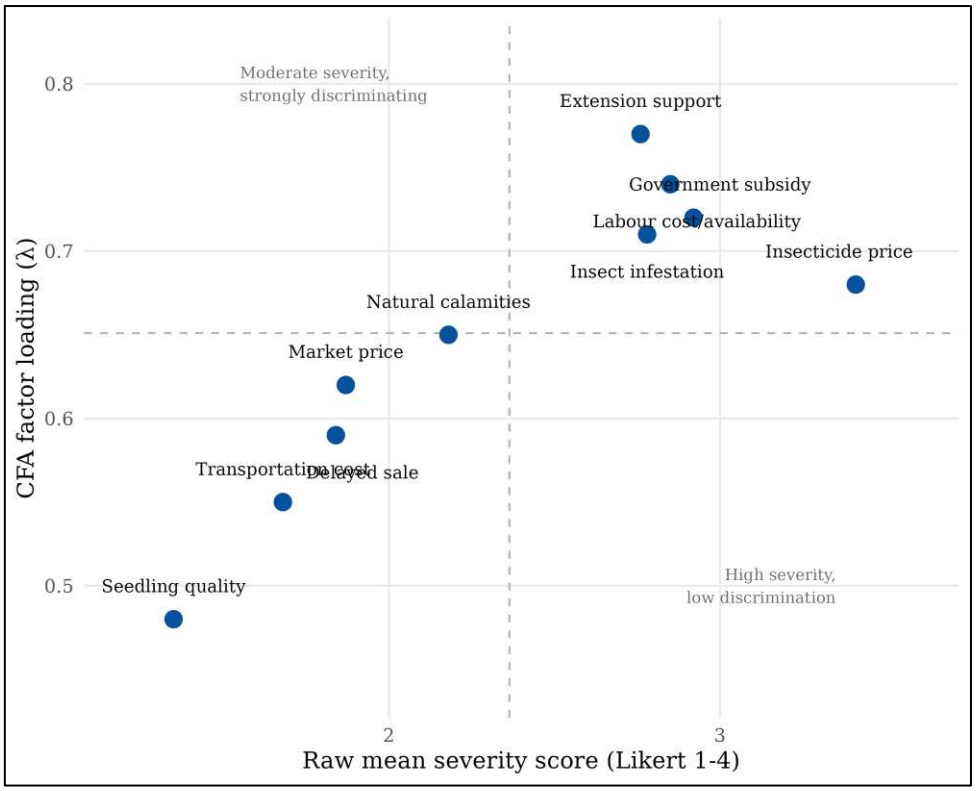


Fig. 9: Divergence between raw mean severity and factor loadings across constraints.

The model-fit statistics also warrant candid interpretation. RMSEA (0.092) is slightly above the conventional 0.08 cut-off [29], and AVE (0.424) is below the 0.50 threshold for strong convergent validity [27], even though Cronbach's alpha and composite reliability both indicate good internal consistency [30]. This indicates that the ten constraints reliably measure one underlying construct while each item still carries substantial item-specific variance, an expected feature of instruments built from heterogeneous practical and market-related problems rather than narrow psychological items [31]; it does not undermine the CFA-based ranking but means it should be read as a robust ordinal guide rather than a claim that the ten constraints are interchangeable.

This pattern echoes other constraint-ranking studies of climate-exposed smallholders, where extension access, labour and input costs, and hazard exposure consistently rank among the most severe barriers [32,33], while market-access items such as transport cost and delayed sale rank lower, as observed here [34], suggesting that in Baniachong the primary barrier to scaling this diversification is institutional support rather than roads or buyers.

5. Conclusions

This study provides the first farm-level evidence on the profitability, resource-use efficiency, and production constraints of BARI Tomato-14 cultivation as a flood-adaptation strategy in the Baniachong *Haor*. Cultivation was profitable on average (BCR = 3.29). Still, profitability was highly unequal across farms, reflecting differentiated flood exposure and input access within a wetland cropping system compressed into a short, safe growing window. Land preparation and fertiliser

expenditure were the two inputs with the largest, most robust productivity elasticities, and both were under-utilised relative to their marginal returns, pointing to binding liquidity rather than technical constraints. Seedling cost showed a statistically insignificant negative association with output, best explained by weak price-quality signalling in local seedling markets. The Constraints Facing Index identified limited extension access, high labour costs, absence of government subsidy, and insect infestation as the most severe barriers, ranked ahead of market-access constraints such as transport cost. BARI Tomato-14 is therefore a technically and economically viable diversification pathway whose benefits are currently constrained less by the crop's inherent risk profile than by the thinness of the institutional support, credit, extension, and quality-assured input supply that reaches farmers between one flood season and the next.

These findings point to four priorities for extension agencies and planners implementing the *Haor* Master Plan in Baniachong and comparable unions. First, because the lack of extension contact was both the most prevalent institutional gap and the most severe constraint by factor loading, expanding extension reach, including personalised digital-advisory channels shown elsewhere to raise smallholder input intensity [18], should be the highest-value intervention available under a limited budget. Second, because land preparation and fertiliser spending are simultaneously the most productive and most under-utilised inputs, targeted seasonal credit or input vouchers timed to the narrow pre-planting window would address a binding liquidity, not persuasion, problem. Third, the seedling findings indicate that investment in certified nursery infrastructure would likely outperform price-based seedling subsidies. Fourth, because a meaningful minority of farms realised negative or marginal returns, weather-indexed microinsurance or contingent credit lines timed to flash-flood events would allow the most flood-exposed unions to participate without bearing catastrophic downside risk. These priorities map directly onto SDG 1, SDG 2, and SDG 13, and provide the *Haor* Master Plan with the crop-specific evidence base its diversification objectives have so far lacked.

6. Policy implications

Beyond the specific measures identified in the Conclusions, translating these findings into practice requires coordinated action across three levels. At the national level, the Bangladesh *Haor* and Wetland Development Board should treat short-duration vegetable diversification, rather than Boro rice alone, as an explicit line item within Master Plan implementation budgets, using the benefit-cost evidence reported here to justify resource allocation toward tomato-growing unions. At the local extension level, the Department of Agricultural Extension should prioritise Baniachong and comparable flood-exposed unions for both in-person and digital-advisory rollout, given that limited extension contact was simultaneously the most common institutional gap and the most severe constraint identified by the Constraints Facing Index. At the financial-service level, agricultural banks, microfinance institutions,

and input suppliers are best placed to design short-tenor, pre-planting credit products and certified-seedling distribution channels, since the profitability of additional land-preparation and fertiliser spending is already established and the binding constraint is access to working capital and reliable planting material rather than technical knowledge.

7. Limitations and directions for future research

This study has several limitations that qualify its findings and point to directions for future research. First, the questionnaire did not include a direct measure of credit access or loan denial, and the cross-sectional, single-season design cannot, in any case, establish causal links between credit access and input under-utilisation, nor can it capture season-to-season variation in flood timing; multi-season panel data collecting credit-access indicators would strengthen causal inference on this point. Second, cost, yield, and price data were self-reported by farmers and may be subject to recall error, although the diagnostic tests did not indicate systematic bias. Third, the purposive selection of Baniachong Upazila, while appropriate for capturing a concentration of BARI Tomato-14 growers, limits the generalisability of the findings to other *Haor* districts with different flood regimes, market access, or institutional coverage. Fourth, the moderate mean VIF (14.92) and the average variance extracted below the conventional 0.50 threshold indicate that individual input elasticities and the Constraints Facing Index should be interpreted as robust ordinal guides rather than precise point estimates. Finally, the near-total male composition of the sample means the findings under-represent women's contributions to tomato production and post-harvest activities. Future research should pursue multi-season panel data, comparative profitability analysis against alternative rabi diversification crops such as maize and mustard, quasi-experimental designs to test the liquidity-constraint hypothesis directly, and gender-disaggregated data collection.

Author contributions

Tukir Ahamed: Conceptualization, methodology, data collection, formal analysis, visualization, writing the original draft, writing – review and editing; **Md. Sherf-Ul-Alam:** Writing – review and editing; **Muhtasim Billah Sajid:** Data collection, data curation, validation; **Tahmid Anam Chowdhury:** Data collection, Study area map preparation; **Abdullah Al Masum:** Data collection, data curation, validation; **Mohammad Aminul Islam:** Supervision and writing – review and editing. All authors have read and approved the final version of the manuscript.

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USD 320), which was primarily allocated to cover essential fieldwork and data collection expenses. No additional financial support was available for this study, and no dedicated funding was provided to cover publication costs.

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Conflict of interest statement

The authors declare that they have no conflict of interest regarding the publication of this paper.

Data availability statement

The data that support the findings of this study are openly available in Figshare at https://doi.org/10.6084/m9.figshare.33545209. The repository contains all datasets (raw and processed versions), complete STATA do-files, log files, output files, STATA project files, the full survey questionnaire and data collection instrument, variable definitions and coding schemes, and supporting documentation necessary to verify the methodology and findings.

Declarations

Ethical approval

This study received ethical approval from the Habiganj Agricultural University Ethical Approval Committee (Approval No. HAU-REC-EAC-000005). The research was conducted in accordance with the ethical requirements and institutional guidelines of Habiganj Agricultural University and internationally recognized ethical principles for research involving human participants, including those outlined in the Belmont Report. The study upheld the principles of respect for persons, beneficence, and justice, with appropriate safeguards for participants' privacy, confidentiality, and voluntary participation. No sensitive personal or health-related information was collected, and participant information was anonymized to prevent identification. Data were handled and stored in accordance with applicable institutional requirements for confidentiality and data protection.

Consent to participate

Written informed consent was obtained from all individual participants included in the study before data collection. Participants were informed of the research's purpose, and their participation was entirely voluntary.

Consent to publish

Not applicable.

Clinical trial number

Not applicable, as this study does not involve any clinical trial.

References

[1] Kabir MS, Akther R, Islam S, Rahman S, Sayadat N, Banik B (2024) Climate change dynamics and adaptation strategies: insights from Dingapota *Haor* farmers in Bangladesh. Discover Agriculture 2:22. https://doi.org/10.1007/s44279-024-00027-0

[2] Islam MM (2024) Unravelling the complexities of wetland agriculture, climate change, and coping mechanisms: an integrative review using economics and satellite approaches. Environment, Development and Sustainability 28:5967–5999. https://doi.org/10.1007/s10668-024-05152-w

[3] Baishakhy SD, Islam MA, Kamruzzaman M (2023) Overcoming barriers to adapt rice farming to recurring flash floods in *Haor* wetlands of Bangladesh. Heliyon 9(3):e14011. https://doi.org/10.1016/j.heliyon.2023.e14011

[4] Hoq MS, Uddin MT, Raha SK, Hossain MI (2022) Determinants of households' livelihood diversification strategies to adapt to natural hazards: evidence from ecologically vulnerable *Haor* region of Bangladesh. Natural Hazards 114(3):3255–3291. https://doi.org/10.1007/s11069-022-05514-5

[5] Ruba UB, Talucder MSA, Zaman MN, Montaha S, Tumpa MFA, Duel MAK, Puja RS, Triza AH (2024) The status of implemented climate smart agriculture practices preferred by farmers of *Haor* area as a climate resilient approach. Heliyon 10(4):e25780. https://doi.org/10.1016/j.heliyon.2024.e25780

[6] Hoq MS, Raha SK, Hossain MI (2021) Livelihood vulnerability to flood hazard: understanding from the flood-prone *Haor* ecosystem of Bangladesh. Environmental Management 67(3):532–552. https://doi.org/10.1007/s00267-021-01441-6

[7] Majumder MK, Rahman MS, Mondal RK, Akter MS (2024) Climate-smart agriculture and food security in climate-vulnerable coastal areas of Bangladesh. Heliyon 10(22):e39885. https://doi.org/10.1016/j.heliyon.2024.e39885

[8] Bangladesh *Haor* and Wetland Development Board (2012) Master Plan of *Haor* Area (Vols I–II). Ministry of Water Resources, Government of the People's Republic of Bangladesh

[9] McGaghie WC, Bordage G, Shea JA (2001) Problem statement, conceptual framework, and research question. Academic Medicine 76(9):923–924. https://doi.org/10.1097/00001888-200109000-00021

[10] Cochran WG (1977) Sampling Techniques, 3rd edn. John Wiley and Sons, New York

[11] Dillon JL, Hardaker JB (1993) Farm Management Research for Small Farmer Development, 2nd edn. Food and Agriculture Organization of the United Nations, Rome

[12] Miah MAM, Hardaker JB (1988) Fertilizer Use and Foodgrain Production in Bangladesh. Bangladesh Agricultural University, Mymensingh

[13] Dhawan KC, Bansal PK (1977) Resource-use efficiency and marginal productivity analysis in Punjab agriculture. Indian Journal of Agricultural Economics 32(3):22–31

[14] Dewett KK (2005) Modern Economic Theory, 22nd edn. S. Chand and Company, New Delhi

[15] Breusch TS, Pagan AR (1979) A simple test for heteroscedasticity and random coefficient variation. Econometrica 47(5):1287–1294. https://doi.org/10.2307/1911963

[16] Ramsey JB (1969) Tests for specification errors in classical linear least-squares regression analysis. Journal of the Royal Statistical Society: Series B 31(2):350–371. https://doi.org/10.1111/j.2517-6161.1969.tb00796.x

[17] Shapiro SS, Wilk MB (1965) An analysis of variance test for normality (complete samples). Biometrika 52(3/4):591–611. https://doi.org/10.1093/biomet/52.3-4.591

[18] Rajkhowa P, Qaim M (2021) Personalized digital extension services and agricultural performance: evidence from smallholder farmers in India. PLOS ONE 16(10):e0259319. https://doi.org/10.1371/journal.pone.0259319

[19] Das S, Jahan M (2022) Production and profitability intervention of summer hybrid tomato: a farm level review in Bangladesh. American Journal of Economics and Business Administration 14(1):21–30. https://doi.org/10.3844/ajebasp.2022.21.30

[20] Mitra S, Sharmin S (2019) Risk attitudes and financial profitability of tomato farmers: a study in Bangladesh. Journal of Agricultural Sciences – Sri Lanka 14(3):210–222. https://doi.org/10.4038/jas.v14i3.8604

[21] Biswas R, Molla MMU, Faisal-E-Alam M, Zonayet M, Castanho RA (2023) Profitability analysis and input use efficiency of maize cultivation in selected areas of Bangladesh. Land 12(1):23. https://doi.org/10.3390/land12010023

[22] Kapeleka JA (2024) Quantification of pesticide dosage and determinants of excessive pesticide use in smallholder vegetable production systems in Tanzania. Heliyon 10(23):e41070. https://doi.org/10.1016/j.heliyon.2024.e41070

[23] Wonde KM, Tsehay AS, Lemma SE (2022) Training at farmers training centers and its impact on crop productivity and households' income in Ethiopia: a propensity score matching (PSM) analysis. Heliyon 8(7):e09837. https://doi.org/10.1016/j.heliyon.2022.e09837

[24] Kosim M, Aji JMM, Hapsari TD (2021) The impact of agricultural extension on productivity of smallholder sugarcane farmers in East Java. IOP Conference Series: Earth and Environmental Science 892(1):012009. https://doi.org/10.1088/1755-1315/892/1/012009

[25] O'Brien RM (2007) A caution regarding rules of thumb for variance inflation factors. Quality and Quantity 41(5):673–690. https://doi.org/10.1007/s11135-006-9018-6

[26] Gujarati DN, Porter DC (2009) Basic Econometrics, 5th edn. McGraw-Hill/Irwin, New York

[27] Fornell C, Larcker DF (1981) Evaluating structural equation models with unobservable variables and measurement error. Journal of Marketing Research 18(1):39–50. https://doi.org/10.1177/002224378101800104

[28] Ali MP, Kabir MMM, Haque SS, Qin X, Nasrin S, Landis D, Ahmed N (2020) Farmers' behaviour in pesticide use: insights study from smallholder and intensive agricultural farms in Bangladesh. Science of the Total Environment 747:141160. https://doi.org/10.1016/j.scitotenv.2020.141160

[29] Hu L, Bentler PM (1999) Cutoff criteria for fit indexes in covariance structure analysis: conventional criteria versus new alternatives. Structural Equation Modeling 6(1):1–55. https://doi.org/10.1080/10705519909540118

[30] Cronbach LJ (1951) Coefficient alpha and the internal structure of tests. Psychometrika 16(3):297–334. https://doi.org/10.1007/BF02310555

[31] Kline RB (2016) Principles and Practice of Structural Equation Modeling, 4th edn. Guilford Press, New York

[32] Pickson RB, He G (2021) Smallholder farmers' perceptions, adaptation constraints, and determinants of adaptive capacity to climate change in Chengdu. SAGE Open 11(3). https://doi.org/10.1177/21582440211032638

[33] Khonje MG, Tambo JA, Taylor B, Day C, Williams F (2025) Provision of pest alerts is associated with better farm performance in Africa. Pest Management Science 82(1):340–347. https://doi.org/10.1002/ps.70196

[34] Kaiser N, Barstow CK (2022) Rural transportation infrastructure in low- and middle-income countries: a review of impacts, implications, and interventions. Sustainability 14(4):2149. https://doi.org/10.3390/su14042149

[35] Bhattacharjee P, Werner M (2026) Social reproduction and agrarian change: gendered harms in Bangladesh's vegetable transition. Agriculture and Human Values 43(1):1–17. https://doi.org/10.1007/s10460-025-10827-9

[36] Adéchian SA, Baco MN (2025) How does land tenure security contribute to the sustainable development of rural households? Evidence from Benin (West Africa). Frontiers in Sustainable Food Systems 9:1621537. https://doi.org/10.3389/fsufs.2025.1621537