Research Article

Assessing Horticultural Crop Production and Profitability: A Comparative Economic Evaluation of Four Promising Fruits Cultivated in Medium-Lowland Areas of Bangladesh

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Abstract | The cultivation of high-value horticultural crops presents a substantial opportunity to enhance agricultural productivity and profitability in medium- to low-land regions of Bangladesh. This experiment was conducted to assess the economic viability of four promising fruit crops -dragon fruit, jujube, mango, and guava in medium-lowland regions. Primarily, data were collected from 180 farmers throughout key cultivating areas for calculating profitability. The economic indicators, such as the benefit-cost ratio (BCR) and returns to scale, employing Cobb-Douglas production function analysis, were utilized to calculate profitability matrices. Data were analyzed using MS Excel and RStudio version R 4.3.2. All fruits unveiled robust economic possibilities with BCR values >1; dragon fruit headed with a BCR of 2.36, followed by jujube (1.97), mango (1.91), and guava (1.67). Moreover, returns to scale analysis ratified encouraging returns among all horticultural fruits, where dragon fruit (1.68), mango (1.32), jujube (1.29), and guava (1.22) signify the potential of large-scale and optimized production. Significant input coefficients were noted for the input cost, such as land preparation, human labor, planting materials, support materials, fertilization, and insecticides across all fruits ($p < 0.001$), dragon fruit exhibited the maximum individual input responsiveness with the values of 0.25, 0.27, 0.15, 0.22, 0.29, and 22 respectively. Based on all assessed economic indicators, dragon fruit emerged as the most suitable and high-performing horticultural crop for the medium-lowland regions in Bangladesh. These findings would support the targeted policy makers, together with input subsidies, training, and value chain development, to augment dragon fruit cultivation along with converting medium-lowlands into centers of high-return horticultural farming.

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Introduction

Agricultural production systems in Bangladesh have conventionally been categorized by a substantial dependency on rice farming, particularly in the medium-lowland areas, which account for a sizable portion of arable land (Nasim *et al*., 2017). Over the past two decades, a combination of declining rice profitability due to labor shortages, low crop diversification, and augmented production risks associated with climate variability (Hossain *et al*., 2017; Sarkar *et al*., 2021; Emran *et al*., 2022) that's why such types of agricultural land have gradually shifted toward high-value horticultural crops (Malek *et al*., 2012; Monshi *et al*., 2015; Jamal *et al*., 2023). Crop diversification has emerged as a key strategy for developing rural employment, reducing rural poverty, ensuring food and nutritional security, and promoting sustainable land use, encouraging long-term economic growth, particularly in emerging economies like Bangladesh (Rahman *et al*., 2024; Ramana *et al*., 2025).

In Bangladesh, agricultural land is divided into five types based on elevation and flooding depth during the monsoon season: highland, medium-highland, medium-lowland, lowland, and very lowland (Huq & Shoaib, 2013). Highlands are usually used for house construction as well as homestead fruit cultivation, while medium highlands are suitable for cultivating rabi crops, especially wheat, maize, potato, and vegetables (Siddique *et al*., 2021). Some areas of the medium-lowland are also used for vegetable agriculture, followed by highland irrigated rice, while lowland and very lowlands are utilized for rice-based farming (Uddin *et al*., 2019; Yesmin *et al*., 2022; Tabassum *et al*., 2023). To maximize long-term profitability, farmers are shifting their attention away from grain crops to fruit cultivation, which includes both native and exotic varieties (Sajid *et al*., 2022). Horticulture fruits, predominantly mango, jujube, malta (oranges), strawberries, and dragon fruit, are achieving popularity in both lowland and medium-high areas, and farmers are substituting horticulture fruit crops instead of cereal crops to increase yields and market demand (Das *et al*., 2022).

Bangladesh's horticulture industry is rapidly increasing and has huge potential, driven by increased urban demand, improved production technology, and suitable climatic conditions (Ahmed *et al*., 2025). Fruit yield has risen by an average of 11.5%, positioning it in the top 10 countries. Therefore, Bangladesh has the potential to become a major player in global fruit exports soon with the right government policies and innovative farmer efforts (Rashid *et al*., 2023). Despite ample opportunities in indigenous fruit cultivation, Bangladesh continues to rely largely on imports to fulfill domestic demand (Ahmed *et al*., 2025). According to current estimates, domestic production accounts for roughly 40% of total fruit consumption in the country, with the remainder imported from South Africa, Brazil, China, Australia, India, Pakistan, and Egypt (Islam *et al*., 2020). To reduce reliance on exports, governments and corporations should invest in advanced technologies to elevate fruit cultivation in medium-lowland areas to an industrial scale (Ruma *et al*., 2023). Furthermore, the government and individuals should launch research programs to boost economic returns.

However, performance evaluation of horticulture fruits such as dragon, mango, guava, and jujube is quite limited, particularly in medium-lowland agroecology (Ruma *et al*., 2023). Most earlier studies revealed greater horticultural development narratives and single-crop profitability evaluations, often without using detailed econometric methodologies to account for input-output relationships. For example, Hasan *et al*. (2014) estimated summer vegetable profitability in Bangladesh using benefit-cost ratios, and Hajong *et al*. (2018) evaluated tomato cultivation through gross margin analysis, both without estimating production elasticities. Although some recent works, such as Kaysar *et al*. (2019) on papaya and Khatun *et al*. (2019) on strawberry, used the Cobb-Douglas production function model and marginal productivity analysis; nevertheless, such techniques are still restricted in horticulture research. So, the current study employed a widely accepted analytical framework, the Cobb-Douglas production function model, which is used in agricultural economics to calculate the gross returns, returns to scale, and input elasticity, all of which are crucial for understanding cost-efficiency and profitability (Billah, 2022; Sinha, 2023; Mondal & Taku, 2025). By integrating both profitability analysis and production function estimation, this study endeavors to provide a comprehensive comparative evaluation of mango, jujube, guava, and dragon fruit cultivation in Bangladesh.

The study aims to assess the cost structures, gross returns, and benefit-cost ratios associated with each fruit crop; estimate the production elasticities of key inputs or returns to scale, and provide policy and practical recommendations for optimizing horticultural production strategies in medium-lowland regions. The findings are intended to benefit farmers, extension agencies, and policymakers in Bangladesh by contributing to the larger goal of agricultural diversification, income enhancement, and sustainable rural development.

Methodology

Study area and crop selection

The study was carried out in the chosen medium-lowland regions of Cumilla and Chadpur districts in Bangladesh for their agro-ecological qualities that are ideal for horticultural fruit production (Figure 1). Four horticultural fruit crops, such as mango (*Mangifera indica* L.), jujube (*Ziziphus mauritiana* L.), guava (*Psidium guajava* L.), and dragon (*Hylocereus undatus*), were chosen based on their agronomic adaptability, market potential, and documented expansion tendencies in the medium-lowland agricultural system.

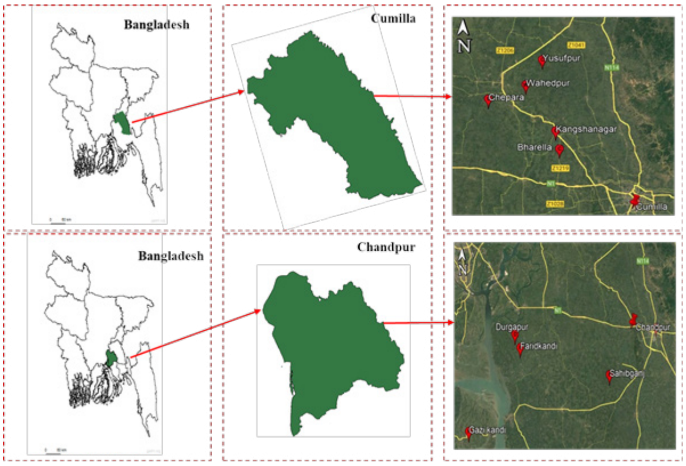

Figure 1: *Geospatial overview of the study regions in Cumilla (top panel) and Chandpur (bottom panel) districts of Bangladesh. The illustration progresses from national-level mapping to district boundaries and high-resolution satellite imagery, pinpointing the specific locations surveyed. This spatial delineation underpins the empirical framework for the agro-economic and production analysis conducted in the study.*

Sampling design and data collection

Multistage stratified random sampling was used to collect 180 samples from different agricultural farms in 5 villages under the Cumilla district and 4 villages under the Chandpur district, Bangladesh (Figure 2). Before the study, a pre-test of the questionnaire was conducted to improve the final questionnaire. In the first stage, two districts were purposely selected considering the agricultural ecology in the medium-lowland area. In the second stage, four representative upazilas were randomly picked from the two selected districts. In the third phase, 9 villages were selected from 4 different upazilas using simple random sampling methods. Finally, in phase 4, a stratified random sampling method was used to choose 20 farmers from each village (Figure 2).

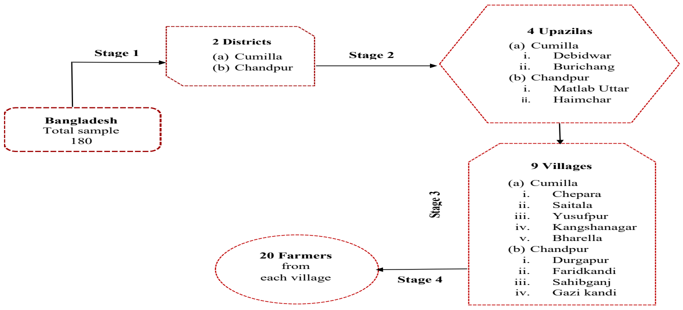

Figure 2: *Multi-stage stratified sampling framework was employed in the study. The sampling process was conducted in four stages: (1) selection of two districts of Bangladesh, Cumilla and Chandpur; (2) selection of four upazilas under the two districts; (3) identification of nine representative villages; and (4) random selection of 20 farmers from each village, resulting in a total sample size of 180 respondents. This structured approach ensured regional diversity and enhanced the robustness of the agro-economic analysis.*

Analytical framework

Cobb-Douglas production function specification

The production efficiency and input-output relationship were modeled using the Cobb-Douglas production function, owing to its well-established applicability in agricultural production studies and its capability to estimate input elasticities directly (Mondal & Taku, 2025). This function was chosen based on the best fit. The general form of the Cobb-Douglas production function was formulated by using the formula introduced by Cobb & Douglas (1928).

$$Y = A \sum_{i=1}^{n} Xi^{bi} \times e^{\mu}$$

An extension of our specified model is

$$Y = X_1^{b1} X_2^{b2} X_3^{b3} X_4^{b4} X_5^{b5} X_6^{b6} X_7^{b7} X_8^{b8} X_9^{b9} \mu$$

After logarithmic transformation, the linear form estimated becomes:

$$\ln Y = \ln a + b_1 \ln X_2 + b_2 \ln X_2 + b_3 \ln X_3 + b_4 X_4 + b_5 \ln X_5 + b_6 \ln X_6 + b_7 \ln X_7 + b_8 \ln X_8 + b_9 \ln X_9$$

Where, Y = Gross return (Tk. ha^{-1}), X_1 = Land preparation cost, X_2 = Human labor cost, X_3 = Planting materials cost, X_4 = Support materials cost, X_5 = Manure cost, X_6 = Fertilization cost, X_7 = Fencing cost, X_8 = Irrigation cost, X_9 = Insecticides cost. ln = Natural logarithm; a = Constant/Intercept; b_1, b_2… b_9 = Coefficients of the respective variables; and μ = Error term.

The coefficient of determination (R^2) is an important statistic in regression analysis that indicates how well a model explains variability in the dependent variable. The coefficient of determination was calculated using the formula given by Pearson (1896).

$$\text{Coefficient of determination, } R^2 = 1 - \frac{RSS}{TSS}$$

Where, RSS = sum of squared residuals, TSS = total sum of squares.
The accuracy of the model was assessed by employing the formula of normality test of the residual introduced by Shapiro & Wilk (1965).

$$W = \frac{\left(\sum_{i=1}^{n} a_i x_{(i)}\right)^2}{\sum_{i=1}^{n}(x_i - \bar{x})^2}$$

Where, the numerator is the square of a weighted sum of the ordered sample values, the denominator is the usual estimate of variance (sum of squared deviations from the mean). If *W* is close to 1, the data are likely normal. If it is significantly smaller than 1, suggesting deviation from normality.

For more precise analysis, Anderson-Darling normality was used, which was introduced by Anderson & Darling (1954).

$$A^2 = -n - \frac{1}{n}\sum_{i=1}^{n}[(2i-1)(\ln F(X_i) + \ln(1 - F(X_{n+1-i})))]$$

Where, $F(X_i)$ is the theoretical CDF (e.g., standard normal) evaluated at the ordered data point. The test emphasizes discrepancies in the tails of the distribution more than other tests like the Kolmogorov-Smirnov test.

Economic viability assessment

The total cost of various fruits was calculated by adding up the costs of land preparation, human labor, planting materials, support materials, manure and fertilizers, fence, irrigation, and pesticides. This allowed for the estimation of overall production costs, gross return, and net return. Gross return was calculated by multiplying the market price by the produced yield per hectare. The gross return formula was formulated by Gittinger (1972).

$$\text{Gross return, } GR = \Sigma\, Q \times P$$

Where, GR = Gross return from product (Tk. ha^{-1}); Q = Quantity of the product; P = Average price of the product (Tk. ha^{-1}).

Net return was the difference between gross return and total production costs.

$$\text{Net return, } NR = \Sigma(GR - TC)$$

Where, GR = Gross return from product (Tk. ha^{-1}); TC = Total cost (Tk. ha^{-1}).

BCR is a relative metric that compares benefit to cost. The BCR was calculated as the ratio of gross profits to gross costs. The formula for calculating BCR (undiscounted), formulated by Baracskay (1998), is given below:

$$\text{Benefit cost ratio, } BCR = \frac{\text{Gross return}}{\text{Total cost}}$$

Statistical analysis

All statistical analyses were assessed using RStudio version R 4.3.2 (R Core Team, 2023), with except for the bar graph, which was examined using Microsoft Excel. A log-linear model was estimated using Ordinary Least Squares (OLS), with all variables transformed using the natural logarithm (log ()) function. The model was assessed and fitted using the linear model (lm) function in RStudio. The model's effectiveness was estimated using key diagnostic metrics, such as the coefficient of determination (R^2), F-statistic, and p-values for individual coefficients. Residual diagnostics were conducted to assess homoscedasticity and normality to validate the assumptions of linear regression.

Results and Discussion

Cost and returns of horticultural fruits

The production cost is a key component of a farm's budget, and it serves as the foundation for assessing the economic viability and sustainability of horticultural fruit crop improvement from the producers' perspective. Precise cost appraisal enables the identification and assessment of all input categories, including land preparation, human labor, planting materials, support materials, fences, irrigation, fertilizer, manure, and pesticide costs. Efficiently evaluating production costs not only informs cost-effectiveness analysis but also helps farmers make decisions about input optimization, risk management, and resource allocation (Adnan *et al*., 2023). These cost-return analyses are crucial for guiding farmers and policymakers toward efficient and successful horticultural fruit production.

Land preparation cost

The substantial input costs associated with preparing the land for fruit orchard construction affect fruit crop production. The collected data on land preparation varied significantly among the samples, which could be attributed to orchard size, geography, and preparation technique, but land preparation costs were nearly identical for all crops, except dragon fruit, which had a slightly higher cost, as shown in the first column of each panel (Figure 3). The main reason for the increased land preparation expenditures in this study was the necessity for land cleaning, soil excavation, plowing, and soil leveling (Table 1). The observed land preparation costs for dragon, mango, guava, and jujube were 54500 Tk. ha^{-1}, 49500 Tk. ha^{-1}, 44500 Tk. ha^{-1}, and 39500 Tk. ha^{-1}, respectively (Figure 4). The typical land preparation cost for horticultural fruit crops in Bangladesh is roughly Tk. 6,239 per hectare (Kaysar *et al*., 2019), but the current study's land preparation cost is substantially higher, possibly due to the medium-lowland, which is prone to seasonal waterlogging, especially during the monsoon. Farmers are compelled to raise high mounds or ridges, a process that demands additional excavation cost, levelling cost, and substantially increases the cost of land preparation (Dasgupta *et al*., 2010; Ahmed & Ambinakudige, 2023). The coefficients of land preparation for mango, jujube,

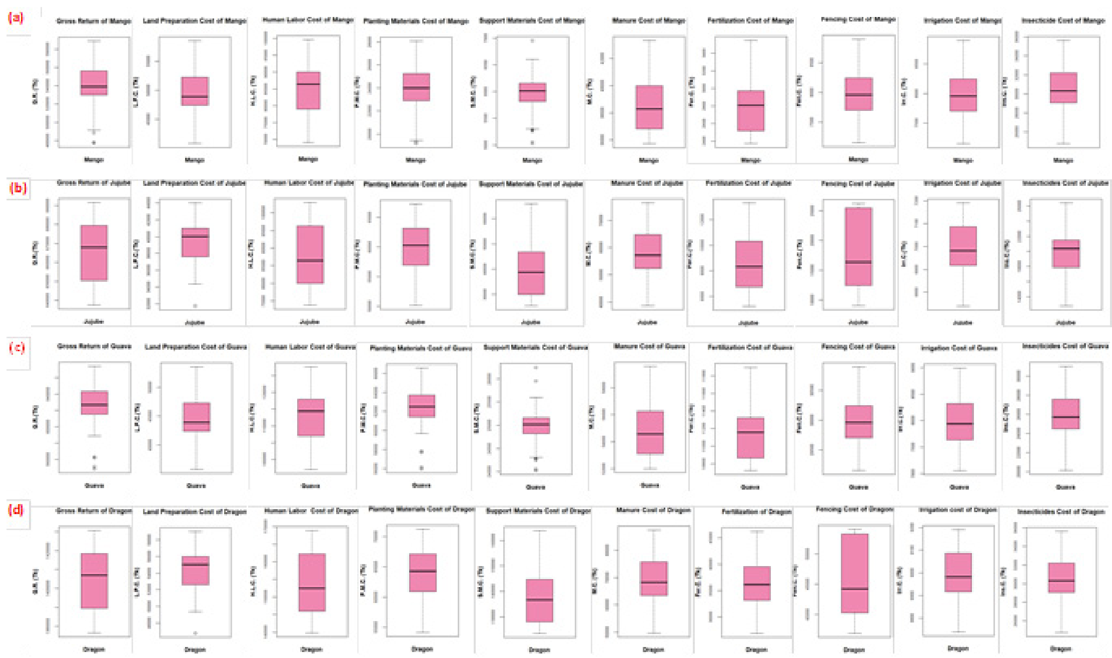

Figure 3: *Boxplots proving the distributional characteristics of gross returns and eight key cost components-land preparation, human labor, planting materials, support materials, manure, fertilizer, fencing, irrigation, and insecticides for the cultivation of (a) mango, (b) jujube, (c) guava, and (d) dragon fruit in Bangladesh. Each subfigure represents 45 empirical data points collected from fruit-producing farms across multiple locations. The interquartile range (IQR) is used to describe variability, with median values highlighting central tendencies in cost and return structures. The visualization was used to understand resource allocation patterns, cost-efficiency relationships, and comparative profitability across diverse horticultural systems.*

guava, and dragon were 0.23, 0.24, 0.20, and 0.25, respectively, at a 1% significance level (Table 2). It means that a one-percent rise in human labor costs, while other parameters remain constant, would boost gross returns 0.23, 0.24, 0.20 and 0.25 %, respectively. Thus, land preparation has a substantial impact on returns to scale and the Cobb-Douglas production function.

Table 1: *Comparative economic assessment of input use and returns for mango, jujube, guava, and dragon fruit production.*

Items	Mango				Jujube				Guava				Dragon			
	Qunt. ha^{-1}	Unit	Price (Tk.)	Total amount Tk. ha^{-1}	Qunt. ha^{-1}	Unit	Price (Tk.)	Total amount Tk. ha^{-1}	Qunt. ha^{-1}	Unit	Price (Tk.)	Total amount Tk. ha^{-1}	Qunt. ha^{-1}	Unit	Price (Tk.)	Total amount Tk. ha^{-1}
G.R.	12000	kg	45	540000	9500	kg	70	665000	12500	kg	50	625000	7800	kg	180	1404000
L.P.																
L. C.				3500				3500				3500				3500
S.E.C.				35000				25000				30000				40000
Plowing				3000				3000				3000				3000
Leveling				8000				8000				8000				8000
Total				49500				39500				44500				54500
Human labor cost (man-days)																
S.P.	60		400	24000	30		400	12000	60		400	24000	60		400	24000
Planting	40		400	16000	40		400	16000	40		400	16000	60		400	24000
F.A.	20		400	4000	10		400	4000	10		400	4000	20		400	8000
pruning	-	-	-	-	15		400	6000	60		400	24000	35		400	14000
Weeding	30		400	12000	30		400	12000	30		400	12000	100		400	40000
Har.	50		400	16000	50		400	20000	50		400	20000	80		400	32000
C.M.	60		400	12000	30		400	12000	30		400	12000	30		400	12000
Total				84000				88000				112000				154000
P.M.C.	150		160	24000	1000		80	80000	625		100	62500	1600		40	64000
S.M.C.																
B.P.	150		40	6000	1000		40	40000	625	40		25000				
C.P.													400		225	90000
Tyres													400		120	48000
Total				6000				40000				25000				138000
M.C.	19240	kg	2	38480	29500	kg	2	59000		kg		54750	35000	kg	2	70000
Fer.C.																
Urea	52	kg	27	1404	120	kg	27	3240		kg		4590	480	kg	27	12960
TSP	15	kg	27	405	60	kg	27	1620		kg		2560	300	kg	27	8100
MOP	42	kg	20	840	150	kg	20	3000		kg		3000	590	kg	20	11800
Gypsum	6	kg	55	330	18	kg	55	990		kg		990	70	kg	55	3850
total				2789				8850				11140				36710
Fencing																
S.F.				30000				15000				30000				30000
U.F.				0.00				10000				00.00				16000
total				30000				25000				30000				46000
Irr. C.				8000				7000				8000				9000
Ins. C.				25600				20000				26000				35000

Here, Qunt. = quantity, L.P. = Land preparation, L.C. = Land Clearing, S.E.C. = Soil excavation cost, S.P. = Soil preparation, F.A. = Fertilizer application, Har. = Harvesting, C.M. = Carrying and marketing, P.M.C. = Planting materials cost, B.P. = Bambo poles, C.P. = Cement poles, M.C. = Manure cost, Fer.C.= Fertilizer cost, S.F. = Side fencing, U.F. = Upper fencing, Irr. C.= Irrigation cost, Ins. C.= Insecticides Cost.

Human labor cost

Human labor contributes significantly to the total production expenses of several fruit crops. The data collected on human labor cost varied significantly among the samples and crops (Figure 3). Human labor costs for various farm operations, such as soil preparation, fertilizer application, harvesting, and post-harvesting handling (carrying and marketing), accounted for a significant portion of the overall production cost for dragon, mango, guava, and jujube (Table 1).

The cost of human labor for mango, jujube, guava and dragon production was Tk. ha^{-1} 84000, Tk. ha^{-1} 88000, Tk. ha^{-1} 112000, and Tk. ha^{-1} 154000, respectively (Figure 4). The labor cost for producing fruits in horticulture differs based on the crop, land type, labor availability, pruning, harvesting, carrying, and marketing. Previous research indicated that the horticultural fruit papaya spends Tk. 57,120 Tk. ha^{-1} for human labor costs (Kaysar *et al*., 2019). The current study found that greater labor cost values could be attributed to the agronomic systems of fruit crops. Dragon fruit has the greatest labor cost as it requires more labor than mango or jujube cultivation due to the necessity for pruning, manual pollination, and cement pillar placement (Pavan *et al*., 2025). The coefficients of human labor cost for mango, jujube, guava, and dragon fruit were 0.20, 0.19, 0.16, and 0.27, respectively, implying that land preparation has a significant impact on returns to scale and the Cobb-Douglas production function, whereas dragon fruit gave the highest returns for investing in the labor cost.

Planting materials cost

The cost of planting materials (seedlings or cuttings) accounts for a substantial portion of the initial capital expenditure in fruit orchard creation. This cost varies greatly amongst fruit varieties depending on propagation method, planting density, cultivar selection, transportation, and scale of purchase (Uddin *et al*., 2019, Das *et al*., 2022). A significant difference was observed among the 45 samples collected for all fruits (Figure 3). Conversely, almost similar planting material costs were found among fruits except for jujube. The planting material costs for mango, jujube, guava, and dragon production were Tk. 24000 ha^{-1}, Tk. 60000 ha^{-1}, Tk. 62500 ha^{-1}, and Tk. 64000 ha^{-1}, respectively (Figure 4). Dragon fruit needed the highest per-hectare cost of planting materials because it is primarily propagated via stem cuttings, and each plant requires a robust, disease-free, mature cutting for good establishment. Commercial cultivation necessitates planting an average of 1600 cuttings per hectare and a cutting price (Table 1). Similarly, jujube and guava need high per-hectare plant material costs because of their medium density and high cost. Among the studied fruit crops, mango production requires the least quantity of planting materials because of its low plant population density, which is generally on average 150 trees ha^{-1}. The coefficient of planting material cost was statistically significant at the 1% level. The coefficients of planting materials cost for mango, jujube, guava, and dragon were 0.17, 0.16, 0.12, and 0.15, respectively. According to the coefficient values, all of the fruits demonstrated a significant impact on the production function, where dragon fruit contributed the highest gross return for planting materials which is corroborated by the findings of Ahmed *et al*. (2025).

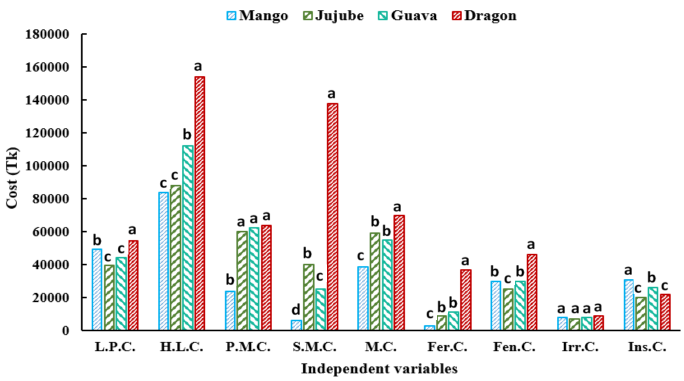

Figure 4: *Relative contribution of key input costs in the production of major horticultural fruits. Here, L.P.C. = Land preparation cost, H.L.C. = Human labor cost, P.M.C. = Planting materials cost, S.M.C. = Support materials cost, M.C. = Manure cost, Fer.C. = Fertilization cost, Fen.C. = Fencing cost, Irr.C = Irrigation cost, Ins.C. = Insecticides cost.*

Manure cost

The cost of manure (ha^{-1}) differs across crops since various fruit cultivars were varied for agronomical characteristics, soil management practices, and nutritional requirements (Figure 3). To maintain fruit crop output and enhance soil fertility, a lot of manure, mostly cow dung, was sprayed throughout the experimental site. Among the studied crops, dragon fruit cultivation had the highest cost due to the cow dung treatment, with an average of Tk. 70000 ha^{-1} in Dragon Fruit, followed by mango Tk. 38400 ha^{-1}, guava Tk.54750 ha^{-1}, and jujube Tk. 59000 ha^{-1} (Figure

4). In the Cobb-Douglas production function, the coefficient for manure cost was found to be negative, showing the opposite relationship between manure expenditure and gross return of chosen fruit crops. Production may be reduced due to overapplication of manure, causing nutritional imbalances, especially in water-retentive medium-lowland soils (Uddin *et al*., 2019). Additionally, applying low quality manure may have produced diseased and poor nutrient-absorbing plants (Pavan *et al*., 2025). Furthermore, improper manure application timing, such as spreading manure too soon or too near to planting time, results in nitrogen loss during the rainy season due to volatilization or leaching (Brummerloh & Kuka, 2023).

Fertilization cost

Dragon fruit offered the highest fertilization cost (Tk. 36,710 ha^{-1}), followed by guava (Tk. 11,140 ha^{-1}), jujube (Tk. 8,850 ha^{-1}), and mango (Tk. 2,789 ha^{-1}) (Figure 4). The production cost coefficients for fertilizer are 0.17, 0.18, 0.21, and 0.29 for mango, jujube, guava, and dragon fruit, respectively, at 1% statistical significance level. This denotes that a one-unit increase in fertilizer cost, with other elements assumed constant, leads to an increase in gross return of 0.17, 0.18, 0.21, and 0.29 %, respectively (Table 2). These coefficient values revealed that the Cobb-Douglas production function is significantly impacted by the fertilizer cost, which has a major effect on the production process (Billah, 2022, Sinha, 2023). Using the proper quantity of fertilizer and minimizing inputs may produce the highest yield and quality, which might help to explain why the fertilizer impact is so important.

Fencing cost

Fencing costs differed considerably among the studied fruit crops; the most expensive was dragon fruit at 46,000 Tk. ha^{-1}, followed by mango and guava at 30,000 Tk. ha^{-1} each, and finally jujube at 25,000 Tk. ha^{-1} (Figure 4). According to the calculated fencing

Table 2: *Estimated input elasticities, model performance metrics, and comparative economic indicators of mango, jujube, guava, and dragon fruit cultivation using the Cobb-Douglas production framework.*

Explanatory variable	Mango			Jujube			Guava			Dragon fruit		
	Coefficient	S.E.	Pr(>|t|)	Coefficient	S.E.	Pr(>|t|)	Coefficient	S.E.	Pr(>|t|)	Coefficient	S.E.	Pr(>|t|)
Intercept	4.64	1.83	0.002^{*}	4.96	1.76	0.003^{**}	4.11	1.45	0.0001^{***}	5.29	1.95	0.0002^{***}
Land preparation cost	0.23	0.08	0.00047^{***}	0.24	0.09	0.00049^{***}	0.20	0.07	0.000054^{***}	0.25	0.06	0.000036^{***}
Human labor cost	0.20	0.11	0.00074^{***}	0.19	0.14	0.00041^{***}	0.16	0.10	0.00017^{***}	0.27	0.11	0.000019^{***}
Planting materials cost	0.17	0.09	0.00061^{***}	0.16	0.07	0.000002^{***}	0.12	0.12	0.000012^{***}	0.15	0.09	0.000043^{***}
Support materials cost	0.18	0.03	0.0016^{***}	0.17	0.07	0.000145^{***}	0.14	0.13	0.04007^{***}	0.22	0.08	0.00002^{***}
Manure cost	- 0.007	0.08	0.39^{ns}	- 0.009	0.11	0.23^{ns}	- 0.009	0.02	0.17^{ns}	- 0.007	0.08	0.12^{ns}
Fertilization cost	0.17	1.58	0.00004^{***}	0.18	1.87	0.0002^{***}	0.21	1.89	0.00003^{***}	0.29	1.34	0.0004^{***}
Fencing cost	0.09	0.06	0.15^{ns}	0.07	0.65	0.04^{*}	0.13	0.61	0.15^{ns}	0.16	1.04	0.03^{*}
Irrigation cost	0.08	1.54	0.45^{ns}	0.06	1.23	0.29^{ns}	0.09	1.11	0.32^{ns}	0.13	1.03	0.23^{ns}
Insecticides cost	0.21	0.75	0.00032^{***}	0.23	0.56	0.00013^{***}	0.18	0.0002	0.00012^{***}	0.22	1.05	0.00019^{***}
Accuracy test												
	Test values		P-values	Test values		P-values	Test values		P-values	Test values		P-values
Test-1	W=0.97		0.49	W=0.93		0.17	W=0.94		0.46	W=0.96		0.24
Test-2	A=0.26		0.62	A=0.41		0.33	A=0.28		0.60	A=0.37		0.41
Model fit test												
R^2	0.80			0.78			0.83			0.87		
Adjusted R^2	0.76			0.73			0.78			0.84		
F-value	18.7^{***}			15.87^{***}			13.65^{***}			21.56^{***}		
GR	540000			665000			625000			1404000		
TC	273369			347350			373890			594210		
NR = (GR-TC)	266631			317650			251110			809790		
BCR = (GR/TC)	1.97			1.91			1.67			2.36		
Return to scale	1.32			1.29			1.22			1.68		

Note: Test-1 = Shapiro-Wilk normality test, Test-2 = Anderson-Darling normality test, GR = Gross return, TC = Total cost, NR = Net return, BCR = Benefit cost ratio. GR, TC, NR, BCR were calculated using the information of Table 3.

cost coefficients in the Cobb-Douglas production function, the guava and mango were statistically non-significant, indicating that the fence had no impact on gross returns or returns to scale. At the 5% level, the jujube and dragon fruit coefficients were both statistically significant, with respective values of 0.13 and 0.16, indicating that a one-unit increase in fencing cost increased gross return by 0.13 and 0.16 percent, respectively, assuming all other parameters remain the same (Table 2). Despite being significant for specific crops, the small quantity of these components indicates that fencing cost has little impact on scale efficiency and the overall production function. Previous empirical research evaluating capital inputs in perennial fruit cultivation under tropical agro-climatic settings has reached similar conclusions. Probably the diminishing benefits of smallholder settings' limited scalability are the reason for the negligible impact of fencing costs (Kapari *et al*., 2023).

Irrigation cost

The empirical analysis of 45 data samples demonstrated no variance across the surveyed fruit farms, indicating a high level of consistency in the production settings under the study (Figure 3). The slight difference in irrigation costs among horticultural fruits, underscores water management strategies are consistent across farms, highlighting that irrigation input may not be a significant differentiator in determining productivity or profitability among the selected fruit crops. Similarly, irrigation expenditures did not differ between fruit harvests. The maximum irrigation costs were recorded at Tk. 9,000 ha^{-1} for dragon fruit, followed by Tk. 8,000 ha^{-1} for mango and guava, and Tk. 7,000 ha^{-1} for jujube (Figure 4). The irrigation cost coefficients for dragon, mango, guava, and jujube were 0.013, 0.006, 0.011, and 0.009, respectively, and were statistically insignificant, indicating that they did not affect the Cobb-Douglas production function or returns to scale (Table 2). The principal cause of non-significance might be attributed to the medium-lowland, where the soil's natural moisture retention capacity and frequent rainfall reduced the need for additional irrigation (Fukai & Mitchell, 2024). These areas frequently hold water for extended periods, maintaining enough soil moisture for agricultural growth, especially during the rainy and post-monsoon seasons, and lowering the importance of irrigation as a yield-determining factor (Bhuyan *et al*., 2023, Demo & Asefa, 2024).

Insecticides cost

Among the studied fruit crops, insecticide application prices were varied significantly. Mango cultivation cost was the highest Tk. 30,600 ha^{-1}, followed by guava (Tk. 26,000 ha^{-1}), dragon fruit (Tk. 22,000 ha^{-1}), and jujube (Tk. 20,000 ha^{-1}) (Figure 4). Mango, jujube, guava, and dragon were estimated elasticity values of 0.21, 0.23, 0.18, and 0.22, respectively, which were all statistically significant at the 1% level and obtained from the Cobb-Douglas production function. These findings indicate that mangoes show the strongest responsiveness, with a 1% increase in pesticide cost leading to a 0.18-0.23% rise in gross returns when all other factors were held constant. This highlights the importance of plant protection measures in maximizing output and financial performance, particularly in pest-prone cropping systems. The fruit fly known as highly invasive and economically harmful pest, poses a danger to mango production since they can result in output losses of up to 80% in extreme circumstances.

These losses can be lessened to a higher degree by using pesticides, suggesting that insects and pests have a major influence on mango farming (Sahithi, 2022, Otieno, 2023). Similarly, dragon fruit is vulnerable to insects that feed on sap, including mealybugs, aphids, and scale insects, which damage the fruit's ability to photosynthesize (Balendres & Bengoa, 2019). Several introduced pathogens, such as bacterial, fungal, and algae species, as well as at least eleven known insect pests, pose a threat to guava production in Bangladesh due to commercial multiplication and trade (Amin *et al*., 2019). According to Choi *et al*. (2023), pests and insects, viz. gall midges, fruit flies, mites, and weevils, can significantly reduce jujube yield and quality. The productivity and profitability of tropical and subtropical agricultural systems depend heavily on the timely and proper large-scale use of pesticides (Ramana *et al*., 2025).

Goodness of fit test

The F-statistic and the coefficient of determination (R^2) were employed to assess how well the model explained the variables under investigation. Both tests adequately evaluated the Cobb-Douglas production functions in terms of their capacity to explain the data. This analysis revealed the R^2 values of 0.87 for dragon fruit, 0.80 for mango, 0.83 for guava, and 0.78 for jujube, which means that the models are able to explain 87, 80, 83, and 78 % of the variation in gross

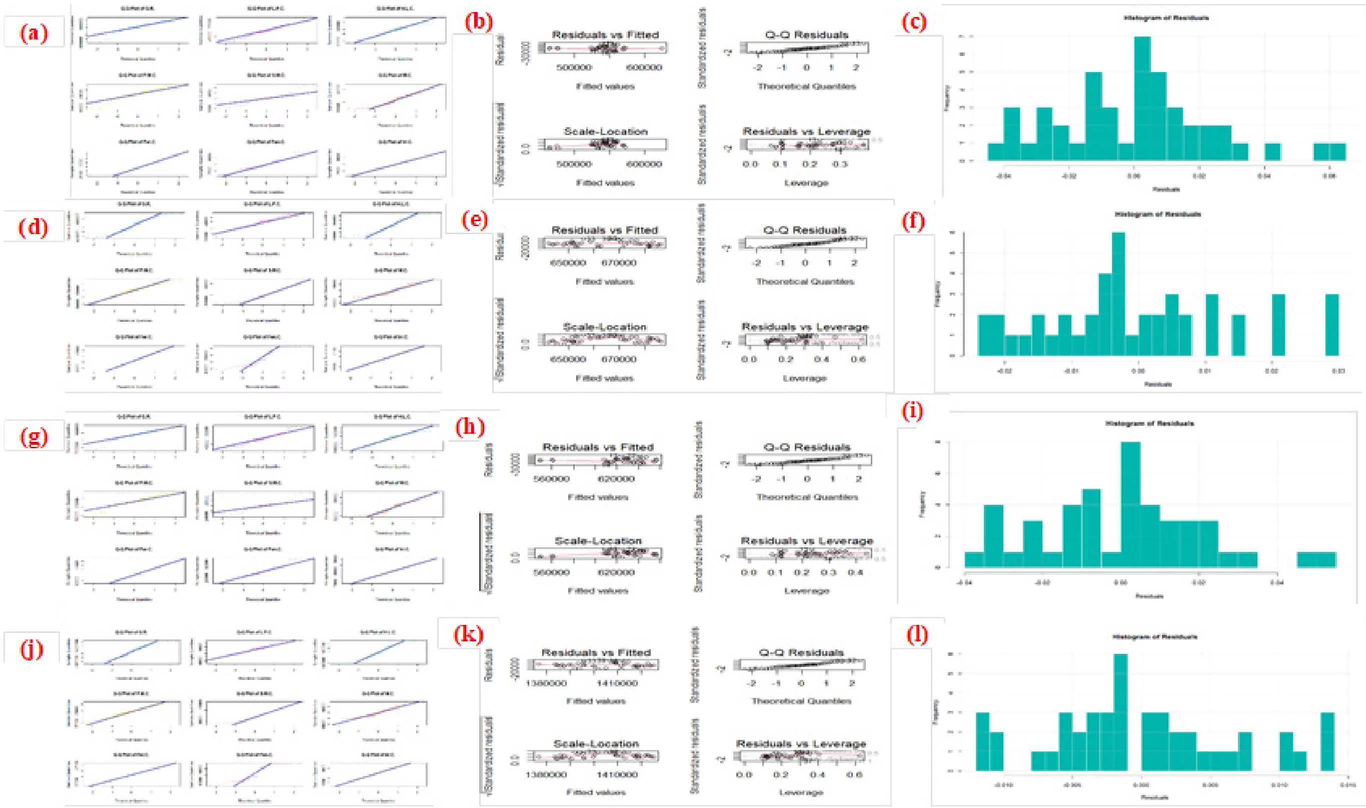

Figure 5: *Comprehensive residual diagnostic analysis to assess the validity of crucial assumptions underlying the classical linear regression framework across different model specifications. Panels (a), (d), (g), and (j) display Quantile-Quantile (Q-Q) plots of standardized residuals to evaluate normality. Panels (b), (e), (h), and (k) provide standard diagnostic plots including residuals versus fitted values, scale-location plots, Q-Q plots, and residuals versus leverage to inspect linearity, homoscedasticity, and the presence of influential observations. Panels (c), (f), (i), and (l) show histograms of residuals to further assess distributional symmetry and potential departures from normality. Together, these diagnostics suggest critical insight into model adequacy and the reliability of subsequent econometric inference.*

return, respectively. The high R^2 value, indicates there is a considerable correlation between the costs of inputs and the output. So, the selected explanatory variables can be used as powerful inputs for increasing the gross return of horticultural crops (Abbas *et al*., 2022, Khanal *et al*., 2024). The goodness of the model is further supported by the F-values. The significant F-value were observed for dragon fruit (21.56), mango (18.70), guava (13.65), and jujube (15.87) at 1% ($p < 0.01$) significance level. In general, the models fit the data and explain the variables, suggesting that input variables change the gross return (Wooldridge, 2016, Li, 2023). Furthermore, this suggests that the models may effectively forecast future productivity and profitability of the studied fruit crops. By utilizing the Cobb-Douglas functional form, the models can be useful for analyzing the economic performance of different fruit crops.

Accuracy test

The Shapiro-Wilk and Anderson-Darling tests were employed to assess the normality of four data sets. The Shapiro-Wilk test resulted in values of W = 0.93-0.97 and p = 0.17-0.49, whilst the Anderson-Darling test generated A = 0.26-0.41 and p = 0.33-0.62. All p-values surpassed the 0.05 threshold (Table 2), indicating adherence to the normality assumption (Razali & Wah, 2011). Further, model robustness was validated using residual diagnostics (Figure 5), such as Q-Q plots, residuals vs fitted values, scale-location plots, Cook's distance, and histograms. These graphs verified normality, homoscedasticity, linearity, and the absence of important outliers, satisfying Gauss-Markov assumptions (Wooldridge, 2016). Model validity was supported by random dispersion, symmetrical distribution, and no high-leverage sites in the residuals. This Production function considers land preparation, human labor, planting materials, support materials, fertilizer and insecticides as key inputs and profitability factors (Abbas *et al*., 2022, Khanal *et al*., 2024). These findings collectively affirm the preference of the model as the most statistically robust specification and highlight the significance of diagnostic assessment in econometric model selection for evidence-based policy and agricultural decision-making (Wooldridge, 2016).

Functional analysis

The estimated Cobb-Douglas production function for mango was:

$\ln Y = 4.64 + 0.23 \ln X_2 + 0.20 \ln X_2 + 0.17 \ln X_3 + 0.18 X_4 - 0.007 \ln X_5 + 0.17 \ln X_6 + 0.09 \ln X_7 + 0.08 \ln X_8 + 0.21 \ln X_9$

The estimated Cobb-Douglas production function for jujube was:

$\ln Y = 4.96 + 0.24 \ln X_2 + 0.19 \ln X_2 + 0.16 \ln X_3 + 0.17 X_4 - 0.009 \ln X_5 + 0.18 \ln X_6 + 0.07 \ln X_7 + 0.06 \ln X_8 + 0.23 \ln X_9$

The estimated Cobb-Douglas production function for guava was:

$\ln Y = 4.11 + 0.20 \ln X_2 + 0.16 \ln X_2 + 0.12 \ln X_3 + 0.14 X_4 - 0.009 \ln X_5 + 0.21 \ln X_6 + 0.13 \ln X_7 + 0.09 \ln X_8 + 0.18 \ln X_9$

The estimated Cobb-Douglas production function for dragon was:

$\ln Y = 5.29 + 0.25 \ln X_2 + 0.27 \ln X_2 + 0.15 \ln X_3 + 0.22 X_4 - 0.007 \ln X_5 + 0.29 \ln X_6 + 0.16 \ln X_7 + 0.13 \ln X_8 + 0.22 \ln X_9$

Returns to scale

Returns to scale were calculated by adding the predicted coefficients for all input variables in the Cobb-Douglas production function. The results revealed that for guava and jujube, the returns to scale were 0.975 and 0.948, respectively, indicating decreasing returns to scale, which means a proportionate increase in all inputs would result in a less-than-proportional rise in output, possibly due to diminishing marginal returns, resource inefficiencies, or coordination difficulties at higher levels of input consumption (Hayes, 2022). The findings exposed that dragon and mango had increasing returns to scale of 1.25 and 1.03, respectively, implying that a proportionate increase in all inputs resulted in a more-than-proportional increase in output. This suggests that production is becoming more efficient on a larger scale (Adnan *et al*., 2023).

Gross return

Gross return, a crucial metric for evaluating the efficiency of crop production systems from an economic standpoint, is calculated using the total monetary value of agricultural output (Cachia *et al*., 2018; Bhuiyan *et al*., 2021). Gross returns for the current study were computed by multiplying the total per-hectare output (converted to kg) by the current market price (Table 1). The analysis revealed that dragon fruit cultivation yielded a gross return of Tk. 1,404,000 ha^{-1}, significantly surpassing that of mango (Tk. 540,000 ha^{-1}), guava (Tk. 625,000 ha^{-1}), and jujube (Tk. 665,000 ha^{-1}), thereby underscoring its superior economic performance. The primary factor contributing to the elevated gross return of dragon fruit is its substantial market value, consistent year-round demand, and the increasing consumer interest in nutrient-rich exotic fruits (Sharma *et al*., 2021). The economic benefits of dragon fruit are enhancing the potential for high-value horticultural crops within varied farming systems to elevate rural incomes and foster sustainable agricultural intensification (Hewett, 2012), notably in the medium-lowland regions of Bangladesh.

Total cost

The overall production cost of input expenditures, including land preparation, planting materials, labor, fertilizers, irrigation, pest management, and post-harvest activities, dictates the economic feasibility of fruit farming systems (Cachia *et al*., 2018). The findings revealed that the overall cost ha^{-1} was calculated by aggregating the costs associated with each variable that elucidated the phenomena (Table 1). The research indicated that the production of dragon fruit incurred the highest total cost, amounting to Tk. 594,210 ha^{-1}. Guava incurred the second-highest total cost at Tk. 373,890 ha^{-1}, followed by jujube at Tk. 347,350 ha^{-1}, and mango at Tk. 273,369 ha^{-1} (Table 2). The substantial initial expenditures on vertical trellising systems, planting materials, specialized irrigation infrastructure, and post-harvest handling and cold storage requirements result in the production cost of dragon fruit being considerably higher than that of other horticultural fruits. This reflects the capital-intensive characteristics of the industry (Sharma *et al*., 2021). Despite the high initial expenses, dragon fruit is still an economically feasible choice for Agri-entrepreneurs for significant yield potential and robust market prices (Chen & Paull, 2019). These findings would help to improve the horticultural sector, as understanding the cost structure of fruit production systems is crucial for strategic resource allocation, investment planning, and the expansion of sustainable fruit agribusiness models in tropical and subtropical nations (Viana *et al*., 2022).

Net return

A key indicator of profitability and overall economic efficiency in agricultural operations is net return, which is the difference between gross return and total production cost (Cachia *et al*., 2018). For each fruit crop in our study, net returns per hectare were determined by subtracting total expenditures from gross returns (Table 1). The findings indicated that dragon fruit yielded the highest net return at Tk. 809,790 ha^{-1}, succeeded by jujube (Tk. 317,650 ha^{-1}), mango (Tk. 266,631 ha^{-1}), and guava (Tk. 251,110 ha^{-1}) (Table 2). The exceptional net return from dragon fruit highlights its potential as a lucrative horticultural commodity, notwithstanding its comparatively elevated production cost. This corresponds with previous research highlighting the economic appeal of high-value exotic fruits in advantageous agro-climatic and market conditions (Chen & Paull, 2019). Incorporating high-return crops into diversified farming systems presents a viable strategy to increase rural incomes, foster agribusiness growth, and attain sustainable intensification, especially in areas experiencing reduced profitability from conventional crops (Adhikari *et al*., 2023).

Benefit-cost ratio

The benefit-cost ratio (BCR) is a prevalent metric in agriculture used to evaluate the profitability and economic efficiency of organizations. This metric is derived by dividing gross return by total production cost (Cachia *et al*., 2018), providing a clear indication of the revenue generated from agricultural investments $dollar^{-1}$ spent. All four fruit crops demonstrated economic viability (BCR > 1), with dragon fruit exhibiting the highest economic efficiency $unit^{-1}$ cost, producing a benefit-cost ratio of 2.36, followed by mango (1.97), jujube (1.91), and guava (1.67). The exceptional BCR of dragon fruit indicates significant consumer appeal, a consistent price-per-unit, and price stability over multiple harvesting seasons, hence increasing profitability (Pavan *et al*., 2025). The results underscore the potential for integrating high-value crops, such as dragon fruit, into various agricultural systems to substantially enhance farm profitability, resource-use efficiency, and long-term economic viability in tropical and subtropical agricultural settings (Nandi *et al*., 2024).

Policy implications

The captivating economic performance of dragon fruit farming exposed in this research-presented a crucial starting point for restructuring horticultural improvement strategies in underutilized medium-lowland regions. Policymakers should highlight dragon fruit in national agricultural investment programs by integrating it into targeted input distribution systems, subsidy schemes, and extension facilities. Accelerating entrance to high-quality planting materials, training in meticulous input use, and post-harvest market infrastructure will be important to revealing large-scale effectiveness and lowering burgeoning obstacles for smallholders. Moreover, aligning these endeavors with climate-resilient farm sector modernization goals, dragon fruit is a strategic crop capable of developing food system diversification, improving rural livelihoods, and strengthening export potential. Regional partnership and international expansion programs may strengthen these benefits by encouraging research, cross-border market integration, and information exchange tailored to tropical fruit systems. Finally, increasing dragon fruit production is a scalable, statistically supported policy strategy to transform economically marginal landscapes into high-value horticultural zone.

Besides profitability analysis, supportive socioeconomic as well as institutional factors are also important for sustaining horticultural crop production in the medium-low land areas. Input support, including farmer's training, financial rewards, marketing facilities with feasible policy, and risk-sharing mechanisms like cooperative marketing or crop insurance, plays a vital role for sustaining farmers' net profit (Kalogiannidis *et al*., 2024; Nandi *et al*., 2024). Integrating these aspects regarding broader discussion surely helps for clearly understanding the economic feasibility of the horticultural fruit cultivation in Bangladesh, where market price and input costs fluctuate continuously (Sarker *et al*., 2022). Regarding these, development of supply chain infrastructure and monitoring market information in time can boost economic profitability, which can help to reduce the risk of market volatility (Quddus & Kropp, 2020). Therefore, an extensive integration of technical efficiency, economic resilience, and appropriate policy support with a stable marketing system can enhance horticultural crop production in the medium-low land areas in Bangladesh.

Conclusions and Recommendations

The present investigation offers an extensive comparative economic assessment of four important horticultural fruit crops like dragon fruit, jujube, mango, and guava cultivated in medium-lowland areas of Bangladesh. The findings of the present study revealed noteworthy differences in total production costs, gross return and net returns and benefit-cost ratio, emphasizing the economic potential of each crop under particular agroecological conditions. Among the four assessed fruits, dragon fruit attained the maximum benefit-cost ratio (2.36) and unveiled the highest returns to scale (1.68), alongside statistically significant responsiveness to important production inputs ($p < 0.001$). These results highlight its superior distributive and input-output efficiency, recommending robust potential for resource leveraged intensification. The positive elasticity coefficients for crucial inputs such as land preparation cost, human labor cost, planting materials cost, support materials cost, fertilization cost, and insecticides cost underscore mechanisms for aimed production gains. Collectively, the findings illustrate a strategic opportunity for policy intervention: by encouraging investment in dragon fruit via input support, value chain expansion, and agronomic training. National endeavors can transform medium-lowlands into cost-effective horticultural growth hubs. For future studies, sensitivity analyses need to be conducted to evaluate profitability under varying market and input price conditions, as well as incorporating financial incentives, marketing strategies, and risk-sharing mechanisms to provide a more comprehensive understanding of economic feasibility and to inform policy development. This empirically supported prioritization presents a scalable model for enhancing smallholder profitability, agricultural sustainability, and rural economic transformation.

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Novelty of statement

This study provides the first comparative economic evaluation of dragon fruit, jujube, mango, and guava in the medium-lowland regions of Bangladesh. By integrating the benefit-cost ratio and Cobb-Douglas production function analysis, it offers novel insights into the profitability and scalability of high-value horticultural crops, highlighting dragon fruit as the most economically viable option.

Author's Contributions

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Muntarina Hussan Mouri: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Resources, Writing- original draft.
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Ahmed Khairul Hasan: Resources, Validation, Writing- review & editing.
Md. Shakhawat Hossain: Resources, Validation, Writing- review & editing.
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Rehenuma Tabassum: Fund acquisition, Conceptualization, Supervision, Investigation, Methodology, Project administration, Resources, Validation, Writing- original draft, Writing- review, editing, and finalizing the manuscript.

Generative AI or AI assisted technology statement
No generative AI or AI assisted technology were used in the preparation of this manuscript.

Conflict of interest
The authors declared that they have no conflict of interest.

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