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Determinants of sustainable high value fruit production: Integrating socio-economic characteristics and climate smart technology adoption at Sitakunda-Mirsarai Upazila, Chattogram, Bangladesh

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Abstract

Background: The transition from traditional subsistence agriculture to High Value Fruit (HVF) cultivation represents a critical pathway for rural microenterprise development and poverty alleviation. However, the socio-economic determinants and technological adoption constraints governing this transition remain insufficiently mapped in localized contexts.

Objective: This study aims to conduct a comprehensive baseline assessment of HVF production economics, climate-smart technology adoption and nutritional diversity among rural microenterprises in the Sitakunda and Mirsarai Upazilas of Chattogram, Bangladesh.

Methodology: A multi-stage systematic random sampling framework was utilized to survey 496 participants, comprising 409 microenterprise farmers (stratified into 10% Ultra-poor, 19% Transitional poor and 71% Enterprising poor). Data were collected *via* Key Informant Interviews (KII) and structured questionnaires. Statistical evaluations were performed using IBM SPSS, applying Chi-square tests at a 5% level of significance (P = 0.05).

Results: The socio-demographic profile revealed agriculture as the primary occupation (87.20%), alongside a 38.90% illiteracy rate. Land tenurial disparities were stark: the ultra-poor operated entirely on leased land (40.08 ± 25.99 decimals), while the enterprising poor held significant proprietary assets (58.26 ± 44.18 decimals). Seasonal cultivation economics showed gross profits peaking at 27.63 ± 55.57 thousand BDT (March-July 2021) but revealed high vulnerability. Technology adoption faced severe cost barriers; 76.50% and 80.70% of farmers deemed bio-pesticides and bio-fertilizers cost-prohibitive, respectively. Value chain bottlenecks were heavily concentrated in post-harvest management (89.80%) and processing (89.10%). Chi-square tests confirmed significant statistical associations between poverty strata and the adoption of climatic adaptive technologies ($\chi^2 = 22.929$, P = 0.011) as well as modern mechanization ($\chi^2 = 39.05$, P = 0.001).

Conclusion: HVF cultivation offers substantial socio-economic opportunities, yet its potential is severely bottlenecked by high input costs, inadequate tissue-culture seedling supply and rudimentary post-harvest infrastructure. Targeted financial interventions and cooperative marketing channels are imperative to ensure equitable integration of ultra-poor and transitional poor households into the commercial HVF value chain.

Keywords: Bio-pesticides, high value fruit, key informant interviews, microenterprise, rural value chains, tissue culture, transitional poverty

Introduction

The global agricultural paradigm is increasingly shifting from the cultivation of traditional, low-margin staple crops toward the commercialization of High Value Fruits (HVF) and vegetables, a transition recognized as a powerful engine for rural poverty alleviation and microenterprise development (Pingali 2015, Reardon and Timmer 2012, Barrett 2008, Hazell and Wood 2008, McCullough *et al.* 2008) [25, 30, 4, 13, 21]. In developing agrarian economies, this shift not only facilitates enhanced income generation but also builds climate resilience among smallholder farming households by diversifying production portfolios and leveraging localized microclimates (FAO 2021, IFAD 2019, FAO 2016, Haggblade and Hazell 2010, Minten and Barrett 2008) [7, 17, 6, 11, 22]. The integration of rural microenterprises into the HVF value chain stimulates upstream and downstream economic activities, fostering employment in agro-processing, logistics and bio-input supply networks (Gomez and Ricketts 2011, Reardon and Minten 2011, Birthal *et al.* 2005, Humphrey and Schmitz 2002) [10, 29, 5, 16]. Furthermore, HVF commercialization plays a fundamental role in improving household nutritional security, directly addressing micro-nutrient deficiencies through increased dietary diversity (Sraboni *et al.* 2014, Ruel and Alderman 2013, Kennedy *et al.* 2011, Arimond and Ruel 2004) [33, 32, 20, 2].

Within the context of Bangladesh, the agrarian structure is characterized by severe land fragmentation, seasonal climate vulnerabilities and a high concentration of ultra-poor and transitional poor households dependent on subsistence farming (Rahman 2017, Minten *et al.* 2013, Rashid *et al.* 2012, Asaduzzaman 2010, Hossain 2004) [27, 23, 12, 3, 15]. To counteract these systemic vulnerabilities, rural development strategies have increasingly prioritized the transformation of subsistence farmers into agro-entrepreneurs capable of engaging with modern, High Value supply chains (Parvin *et al.* 2014, Hassan *et al.* 2010, Ali 2000) [24, 12, 1]. The Chattogram division, specifically the Sitakunda and Mirsarai Upazilas, presents a unique agro-ecological zone with highly favorable topographical and climatic conditions for perennial and seasonal HVF cultivation. Despite this immense localized potential, the regional transition remains fragmented and under-capitalized (Weinberger and Lumpkin 2007) [36].

Critical research gaps persist regarding the localized mechanics of these value chains, particularly concerning the socio-economic determinants that dictate technology adoption across different poverty strata. There is a documented deficiency in the understanding of how ultra-poor and transitional poor farmers access climate-smart technologies, such as bio-pesticides and bio-fertilizers, which are often perceived as cost-prohibitive (Jack 2013, Kassie *et al.* 2011, Suri 2011, Foster and Rosenzweig 2010, Feder *et al.* 1985) [18, 19, 34, 9, 8]. Moreover, the systemic barriers related to the inadequate supply of tissue culture derived HVF seedlings, pervasive post-harvest management losses and disorganized local marketing channels remain poorly quantified in the specific context of Chattogram's rural microenterprises (Reardon 2015, Trienekens 2011, Weinberger and Lumpkin 2007, Birthal *et al.* 2005) [31, 35, 36, 5].

Therefore, this study was designed to execute a comprehensive baseline assessment of the HVF sub-sector in the Sitakunda and Mirsarai Upazilas. The primary objectives were to analytically document the socio-demographic profiles and land tenurial systems of microenterprise producers, quantify the seasonal production economics and profitability of HVF cultivation and map the existing supply chain and value chain inefficiencies. Additionally, the study aimed to evaluate the adoption rates and cost-effectiveness of climate-adaptive agricultural technologies.

Materials and Methods

1. Study Area and Duration

The baseline investigation was conducted in the Chattogram district of Bangladesh, focusing explicitly on the Mirsarai and Sitakunda Upazilas. The study locations encompassed multiple unions and distinct villages representing varying agro-ecological and socio-economic dynamics. Data collection was executed during an extensive five-day field campaign spanning from 27 September 2022 to 1 October 2022.

2. Sampling Design and Sample Size Determination

A multi-stage systematic random sampling framework was deployed to capture a statistically representative cohort from a target population of 5,000 rural microenterprises associated with the Rural Microenterprise Transformation Project (RMTP). The theoretical sample size (n) was calculated using the standard statistical proportion formula:

Sample size (n) =

$$\frac{\frac{z^2 \text{X p} (1-\text{p})}{e^2}}{1+\left\{\frac{z^2 \text{X p} (1-\text{p})}{e^2 \text{N}}\right\}}$$

Based on a 95% confidence interval (z = 1.96), a standard deviation proportion (p = 0.5), a 5% margin of error (e = 0.05) and a total population (N = 5000), the required sample size was initially calculated as 357.

To ensure robust empirical validity and adequately capture the variance across the supply chain, the final empirical sample size was expanded to 496 respondents. This cohort comprised 409 microenterprise beneficiaries stratified into three distinct poverty categories based on standardized regional proportions: Ultra-poor (10%), Transitional poor (19%) and Enterprising poor (71%).

3. Data Collection Mechanisms

Primary data were acquired through the administration of rigorously structured questionnaires and Key Informant Interviews (KII). The studied Upazilas were segmented into blocks and further subdivided into village-level sites to facilitate systematic coverage.

4. Statistical Processing

Quantitative data processing and descriptive statistical aggregations were conducted utilizing Microsoft Excel 2013, which was employed to calculate Means, Standard Deviations (SD), Maximum-Minimum ranges and Interquartile Ranges (IQR) for production economics and land ownership metrics. Advanced inferential statistical analysis was performed using IBM SPSS (Statistical Product and Service Solutions). Cross-tabulations and Pearson's Chi-square (χ^2) tests were executed to ascertain the significance of associations between categorical variables (e.g., poverty strata, occupational frequency, technology adoption). All inferential tests were evaluated at a strict 5% level of significance (P = 0.05).

Results

1. Socio-Demographic Profiling

The geographical distribution of the respondent farmers spanned eight distinct villages across four unions (Table 1). In Mirsarai Upazila, respondents were situated in Wahedpur (9.60%), Talbariya (17.30%) and Tripurapara (7.90%). In Sitakunda Upazila, respondents were located in Shantinagar (15.10%), Chowdhurypara (8.60%), Bashbariya (27.90%), Yakubnagar (7.90%) and a secondary Tripurapara site (5.70%).

Table 1: Geographical distribution of the respondent farmers across villages and unions

Upazila	Union	Number	(%)	Village	Number	(%)
Mirsarai	15 No Wahedpur	39	9.60	Wahedpur	39	9.60
	9 No Mirsarai	102	25.20	Talbariya	70	17.30
				Tripurapara	32	7.90
Sitakunda	3 No Sitakunda	90	22.20	Yakubnagar	32	7.90
				Chowdhurypara	35	8.60
				Tripurapara	23	5.70
	6 No Bashbariya	174	43.00	Bashbariya	113	27.90
				Shantinagar	61	15.10

Table 2: Respondent's age, education and number of family members status

	Age	Number	(%)	Education	Number	(%)	Family members	Number	(%)
Categories	< = 25	63	15.60	Primary	104	25.70	1	26	6.40
	25-35	155	38.30	Secondary	117	29.00	4	188	46.40
	35-45	102	25.20	Above Secondary	26	6.40	6	126	31.10
	45 and Above	85	21.00	Illiterate	157	38.90	8 +	65	16.00

Demographically, the cohort was segmented into four age categories (Table 2): <= 25 years (15.60%), 25-35 years (38.30%), 35-45 years (25.20%) and 45 years and above (21.00%). Educational attainment revealed significant vulnerabilities, with a prevailing illiteracy rate of 38.90%. The remainder of the population possessed primary (25.70%), secondary (29.00%), or above secondary (6.40%) education. Household sizes were predominantly composed of four members (46.40%) and six members (31.10%), with the extremities being single-member households (6.40%) and large households of eight or more members (16.00%).

2. Occupational and Income Dynamics

The primary occupational reliance (Table 3) was overwhelmingly concentrated in agriculture, accounting for 87.20% of the respondents, followed by marginal participation in daily labor (3.70%), private service (4.20%), business (3.70%), farming contact labor (1.00%) and government service (0.20%). Secondary occupational activities exhibited greater diversification, heavily skewed toward business (46.80%) and daily labor (27.70%), followed by agriculture (12.70%), private service (11.40%) and farming contact labor (1.40%).

Table 3: Frequency of primary and secondary occupations among microenterprises

	Primary occupations	Number	(%)	Secondary occupations	Number	(%)
Categories	Agriculture	353	87.20	Agriculture	28	12.70
	Daily Labour	15	3.70	Daily Labour	61	27.70
	Farming Contact Labour	4	1.00	Farming Contact Labour	3	1.40
	Private Service	17	4.20	Private Service	25	11.40
	Govt Service	1	0.20	Govt Service	0	0.00
	Business	15	3.70	Business	103	46.80

Annual household income was broadly categorized into four brackets: <= 10,000 BDT (44.80%), 10,000-25,000 BDT (9.10%), 25,000-50,000 BDT (20.00%) and 50,000+ BDT (26.10%). Income generation pathways, quantified in thousands of BDT annually, were stratified by household contributors:

- **Household Head:** Service generated the highest mean income (78.86 ± 38.09), followed by Business (66.07 ± 101.22), Day Labor (35.98 ± 23.18), Handicrafts (22.50 ± 11.90), Remittance (6.75 ± 3.30) and Others (53.00 ± 18.09).
- **Secondary Male Contributor:** Service (76.54 ± 36.14), Remittance (58.75 ± 57.62), Day Labor (53.38 ± 42.18), Business (39.23 ± 19.26), Handicrafts (0.00 ± 0.00) and Others (66.43 ± 18.87).
- **Secondary Female Contributor:** Day Labor (55.00 ± 7.07), Business (36.67 ± 15.28), Handicrafts (16.66 ± 12.51), with Service, Remittance yielding 0.00 ± 0.00 and Others (45.00 ± 15.28).

3. Land Tenurial Systems

Landholdings, measured in Decimals, demonstrated stark disparities across the predetermined poverty strata. The Ultra-poor group possessed no proprietary land (0.00 ± 0.00 own land) and operated entirely on leased property (40.08 ± 25.99 lease land), resulting in a total landholding of 40.08 ± 25.99. The Transitional poor group exhibited average own landholdings of 25.73 ± 9.56 and leased lands of 61.06 ± 47.70, culminating in total land access of 86.12 ± 47.33. The Enterprising poor controlled the largest assets, with own landholdings of 58.26 ± 44.18 and leased lands of 69.49 ± 64.78, totaling 126.86 ± 74.78 (Table 4).

Table 4: Land tenurial systems across poverty strata (Ultra-poor, Transitional poor, Enterprising poor)

Land Information	Farmers Type					
	Ultra-poor		Transitional poor		Enterprising poor	
Land Type (Decimal)	Mean ± SD	Median	Mean ± SD	Median	Mean ± SD	Median
Own Land	0.00±0.00	0.00	25.73±9.56	25	58.26±44.18	50
Lease Land	40.08±25.99	39.5	61.06±47.7	50	69.49±64.78	50
Total Land	40.08±25.99	39.5	86.12±47.33	77.5	126.86±74.78	110

4. Production Economics (Seasonal and Perennial)

The economic performance of cultivated fruits fluctuated distinctly across three temporal blocks and perennial operations.

Table 5: Cultivated Fruits (March 2021 to July 2021)

Variables	Mean (SD)	Median	Max-Min	IQR
Cultivated land (Decimal)	52.01 (46.06)	40	250 - 4	(75 - 16)
Total Cost of production (investment)	115.03 (913.95)	10	10000 - 1.4	(19 - 5)
Total production (Mt)	1.84 (5.25)	1	100 - 0.13	(2 - 0.6)
Sales price (Mt)	26.72 (11.48)	25	85 - 0.4	(32 - 20)
Total Sales (Income)	38.68 (36.77)	25	240.17 - 3.5	(48 - 15)
Gross profit (BDT)	27.63 (55.57)	11.6	909 - 1	(30- 8)

March 2021-July 2021: Cultivated land averaged 52.01 ± 46.06 Decimals. The total cost of production was substantial at 115.03 ± 913.95 thousand BDT. Total production reached 1.84 ± 5.25 Mt, achieving an average sales price of 26.72 ± 11.48 thousand BDT. Total sales yielded 38.68 ± 36.77 thousand BDT, resulting in a gross profit of 27.63 ± 55.57 thousand BDT (Table 5).

July 2021-November 2021: Average cultivated land was 51.34 ± 41.92 Decimals. Total production cost decreased to 64.58 ± 595.85 thousand BDT. Production volume was 1.67 ± 1.76 Mt with a sales price of 26.33 ± 3.35 thousand BDT. Total sales were 37.14 ± 27.12 thousand BDT, generating a gross profit of 23.65 ± 22.98 thousand BDT (Table 6).

Table 6: Cultivated Fruits (July 2021 to November 2021)

Variables	Mean (SD)	Median	Max-Min	IQR
Cultivated land (Decimal)	51.34 (41.92)	40	300 - 5	(60 - 25)
Total Cost of production (investment)	64.58 (595.85)	8	8500 - 1	(18 - 5)
Total production (Mt)	1.67 (1.76)	1.44	19 - 0.1	(2.1 - 0.76)
Sales price (Mt)	26.33 (13.35)	23.68	80.5 - 0.5	(34 - 15.5)
Total Sales (Income)	37.14 (27.12)	33	161.19 - 0.95	(47 - 18)
Gross profit (BDT)	23.65 (22.98)	17.32	155.92 - 1	(27 - 8)

Table 7: Cultivated Fruits (November 2021 to March 2022)

Variables	Mean (SD)	Median	Max-Min	IQR
Cultivated land (Decimal)	47.99 (44.65)	40	350 - 3	(56 - 20)
Total Cost of production (investment)	10.97 (11.14)	7	120 - 1	(15 - 4)
Total production (Mt)	1.62 (2.59)	0.8	23 - 0.08	(1.8 - 0.5)
Sales price (Mt)	25.59 (11.97)	22.63	78 - 0.6	(30 - 19)
Total Sales (Income)	37.14 (27.12)	33	161.19 - 0.95	(47 - 18)
Gross profit (BDT)	20.71 (41.21)	11.2	654.15 - 0.5	(20 - 6)

November 2021-March 2022: Cultivated land contracted slightly to 47.99 ± 44.65 Decimals. Production costs dropped significantly to 10.97 ± 11.14 thousand BDT. Total production equaled 1.62 ± 2.59 Mt, with a sales price of 25.59 ± 11.97 thousand BDT. Total sales were 37.14 ± 27.12 thousand BDT, yielding a gross profit of 20.71 ± 41.21 thousand BDT (Table 7).

Perennial Crops: The cultivated land area was restricted to 18.07 ± 14.44 Decimals (Table 8). Total production cost averaged 7.74 ± 26.20 thousand BDT. With a production volume of 1.26 ± 2.74 Mt and a sales price of 2.25 ± 5.70 thousand BDT, total sales equated to 24.18 ± 23.33 thousand BDT, returning a gross profit of 18.43 ± 21.81 thousand BDT. The highest cultivated perennial fruits were Mango (37.80%), Guava (27.00%), Teak (19.00%), Jackfruit (16.00%), Litchi (14.30%) and Lemon (13.80%).

Table 8: Perennial crops (March 2021-February 2022

Variables	Mean (SD)	Median	Max-Min	IQR
Perennial crops Cultivated land (Decimal)	18.07 (14.44)	15	128 - 1	(20 - 10)
Perennial crops Total Cost of production (investment) (last one year)	7.74 (26.2)	4	500 - 0.22	(8 - 2.5)
Perennial crops Total production (Mt)	1.26 (2.74)	0.52	45 - 0.02	(1 - 0.4)
Perennial crops Sales Quantity	2.25 (5.7)	0.5	30 - 0.01	(1.23 - 0.3)
Perennial crops Total Sales	24.18 (23.33)	15.75	250 - 0	(30 - 10.5)
Perennial crops Gross profit	18.43 (21.81)	11.25	240 - 0.2	(22 - 6)

5. Technology Adoption Matrix

Access to and utilization of agricultural technologies exposed significant economic barriers. Regarding climatic adaptive technologies, exclusive utilization rates were consistently low (Table 9): Bio-pesticides (39.30%), Bio-fertilizers (41.50%), Fruits bags (9.50%) and Pheromone traps (3.80%). When used in conjunction with other methods, adoption expanded for Bio-pesticides (87.40%) and Bio-fertilizers (92.30%).

Table 9: Use of modern technology (Knowledge on climatic adaptive technology**)**

Categories	Responses		
	Number	Only	With others
Bio Pesticide	354	39.30%	87.40%
Bio Fertilizer	374	41.50%	92.30%
Fruits Bag	86	9.50%	21.20%
Pheromone Trap	34	3.80%	8.40%
Others	53	5.90%	13.10%

However, economic perceptions heavily limited scalability: 76.50% of respondents perceived (Table 10) bio-pesticides as costly (only 10.90% deemed them cost-effective) and 80.70% viewed bio-fertilizers as costly (11.60% cost-effective). For general modern technologies, exclusive reliance on Fruits bags (20.50%), Irrigation (39.80%) and Mechanization (26.70%) was observed (Table 11). The cost perception remained prohibitive, with Irrigation (77.60%), Mechanization (52.60%) and Fruits bags (40.00%) predominantly classified as costly (Table 11).

Table 10: Technology costly or cost effective

Types	Costly		Cost effective		Chi-square	P-value
	No	%	No	%		
Bio Pesticide	310	76.50	44	10.90	11.546	0.042
Bio Fertilizer	327	80.70	47	11.60		
Fruits Bag	80	19.80	6	1.50		
Pheromone Trap	33	8.10	1	0.20		
Others	48	11.90	5	1.20		

Table 11: Use of modern technology and Technology costly or cost effective

Types	Use of modern technology			Technology Costly		Technology Cost effective		Chi-square	P-value
	No	Only (%)	With others (%)	No	%	No	%		
Fruits bag	153	20.50	45.00	136	40.00	17	5.00	9.941	0.041
Irrigation	298	39.80	87.60	264	77.60	34	10.00		
Mechanization	200	26.70	58.80	179	52.60	21	6.20		
Others	97	13.00	28.50	81	23.80	16	4.70		

6. Transportation and HVF processing (Jam/Jelly/ Pickles)

Transport logistics were severely hampered by driver/mechanic trouble (36.40%), rough roads (27.30%), unwanted obstructions (18.20%) and engine failures (18.20%). The frequency of transit motions operated on daily (42.90%), weekly (28.60%) and nightly (28.60%) schedules. Processed HVF product sales were dominated by Jam/Jelly (33.30%) and Pickles (33.30%), whereas Chocolate/Juice/Coffee exhibited the lowest sales margins (16.70%).

7. Supply Chain and Value Chain Mechanics

Structural constraints within the HVF value chain were profound (Fig. 1). Operational bottlenecks were heavily concentrated in Post-harvest management (89.80%), Processing (89.10%), Labor scarcity (86.70%), Technology deficit (86.60%) and Finance shortages (84.20%). Conversely, respondents identified robust opportunities regarding Land availability (92.10%), Sales volume potential (94.30%) and Market pricing (85.10%).

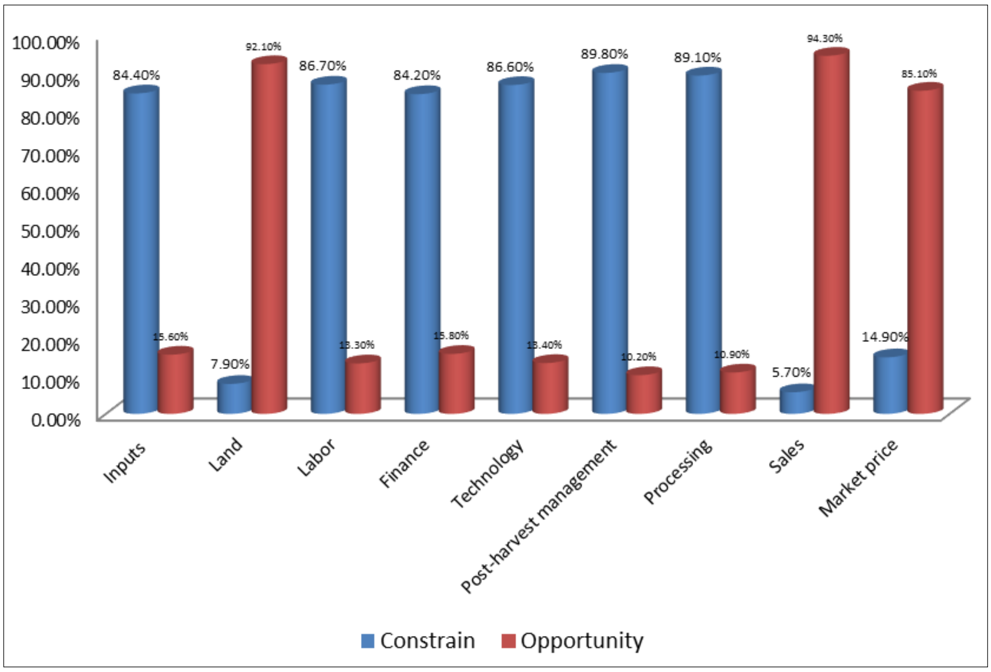

Fig 1: Constrains and opportunity of the quality sapling, bio pesticide, technology etc

8. Statistical Frequencies and Associations

Chi-square analysis elucidated the statistical significance of socio-economic and technological parameters across the poverty gradient (Ultra-poor < Transitional poor < Enterprising poor):

- **Occupational Variations:** Main occupation (χ^2 = 7.778, P = 0.651) showed no significant deviation, whereas Secondary occupation (χ^2 = 17.268, P = 0.027) was statistically significant across strata.
- **Technology Access and Knowledge:** Knowledge regarding climatic adaptive technology access was highly significant (χ^2 = 36.563, P = 0.0004). Conversely, basic modern technology access (χ^2 = 2.795, P = 0.593) and pesticide type knowledge (χ^2 = 2.118, P = 0.347) lacked statistical significance.
- **Technology Application in HVF:** The actual utilization of climatic adaptive technologies (χ^2 = 22.929, P = 0.011) and modern technologies (χ^2 =

39.05, P = 0.001) in HVF fields differed significantly by poverty class, though the application of specific pesticide types did not ($\chi^2 = 6.124$, P = 0.194).

- **Economic Perceptions (Costly vs. Cost-effective):** Statistical significance was observed regarding the cost perceptions of climatic adaptive technologies ($\chi^2 = 11.546$, P = 0.042) and modern technologies ($\chi^2 = 9.941$, P = 0.041). The cost perception of pesticide types showed no significant association ($\chi^2 = 4.441$, P = 0.109).

Discussion

The empirical findings from Sitakunda and Mirsarai Upazilas expose a highly stratified rural microenterprise ecosystem where the transition toward High Value Fruit (HVF) cultivation is dictated heavily by existing socio-economic capital. The observed gradient in land tenurial security wherein the Ultra-poor operate entirely on leased lands (40.08 ± 25.99 Decimals) while the Enterprising poor possess substantial proprietary holdings (58.26 ± 44.18 Decimals) fundamentally shapes risk appetites and investment capabilities. This confirms established agricultural economic theories suggesting that asset poor households are disproportionately barred from the lucrative commercialization of High Value crops due to insurmountable entry barriers and tenure insecurity (IFAD 2019, Minten *et al.* 2013, Pingali 2012, Reardon and Timmer 2012, Hazell 2011, Barrett 2008) [17, 23, 26, 30, 14, 4]. Consequently, while the total production economics across the three seasonal blocks generated consistent gross profits, the high standard deviations within production costs and profits (e.g., 27.63 ± 55.57 thousand BDT in March-July) reflect severe market volatility and the unequal distribution of financial resilience among producers.

The technology adoption matrix further underscores this socio-economic divide. The highly significant statistical association between poverty strata and the practical application of both climatic adaptive technologies (P = 0.011) and modern mechanization (P = 0.001) indicates that technology transfer is failing to reach the most vulnerable demographics. A staggering 76.50% and 80.70% of farmers identified bio-pesticides and bio-fertilizers as cost-prohibitive, respectively. This perception aligns with the broader discourse on smallholder technology adoption, which dictates that without targeted subsidies or robust microcredit interventions, the initial capital expenditures for climate smart inputs prevent widespread integration, leading to suboptimal yields and continued reliance on chemically intensive, ecologically detrimental conventional farming (Jack 2013, Kassie *et al.* 2011, Suri 2011, Foster and Rosenzweig 2010, Minten and Barrett 2008, Feder *et al.* 1985) [18, 19, 34, 9, 22, 8].

Beyond the farm gate, the value chain mechanics reveal crippling systemic inefficiencies. With 89.80% of respondents citing post-harvest management and 89.10% citing processing as primary constraints, it is evident that value addition is stymied by a lack of localized infrastructure. The reliance on fragmented transport logistics plagued by driver trouble (36.40%) and rough roads (27.30%) induces high post-harvest losses and forces farmers to accept suboptimal farm-gate prices from arotders and local collectors. Such logistical friction is a recognized hallmark of developing supply chains, where the absence of cold storage facilities and cooperative aggregation models leaves individual microenterprises exposed to aggressive price arbitrage by intermediary actors (Reardon 2015, Gomez and Ricketts 2011, Trienekens 2011, Birthal *et al.* 2005, Humphrey and Schmitz 2002) [31, 10, 35, 5, 16]. Ultimately, bridging the gap between high market demand and constrained local supply requires a coordinated multi-stakeholder approach to dismantle the financial and infrastructural barriers isolating these rural microenterprises.

Conclusions

The transition to High Value Fruit cultivation in Sitakunda and Mirsarai presents a viable, high potential pathway for rural economic development, demonstrated by the positive gross profit margins recorded across all seasonal blocks. However, the actualization of this potential is sharply constrained by socio-economic stratification. Ultra-poor and transitional poor households face systemic exclusion from maximizing yields due to absolute reliance on leased lands, prohibitive costs of climate smart technologies (bio-pesticides and bio-fertilizers) and catastrophic deficiencies in post-harvest processing infrastructure. While the demand for HVF and processed derivatives (jams, jellies, pickles) remains high, the current value chain structure disproportionately penalizes the primary producer through severe logistical friction and localized market monopolies.

Recommendations

To actualize the commercial potential of the HVF sub-sector and ensure equitable microenterprise transformation, the following targeted interventions are recommended:

1. **For Government and Local Policy Makers**
- Implement immediate infrastructural upgrades focusing on rural road networks to reduce transit-induced post-harvest losses.
- Establish localized, government-subsidized cold storage facilities and fruit shade houses to decouple farmers from immediate, forced post-harvest sales.
- Introduce localized price-monitoring boards to regulate excessive profiteering by intermediary Arotders and wholesale collectors.

2. **For Research Institutes and Sophisticated Laboratories**
- Organizations such as BARI, BFRI and PTCBL must accelerate the production and equitable distribution of tissue-culture-raised HVF seedlings to ensure a continuous, high quality saplings supply.
- Facilitate bi-directional knowledge exchange protocols to match academic crop suitability research with real world, localized soil and climatic challenges faced by farmers.

3. **For Financial and Non-Governmental Organizations (NGOs)**
- Design and deploy specialized microcredit portfolios tailored specifically to the Ultra-poor and Transitional poor, utilizing lenient repayment structures that align with the delayed revenue cycles of perennial HVF crops.
- Subsidize the procurement of essential modern agro-machinery (pumps, harvesters, pruning tools) through NGO backed shared asset or cooperative leasing models.

4. **For Extension Agencies and Farmer Cooperatives**

- Institute rigorous, continuous capacity building workshops focused on Integrated Pest Management (IPM), pheromone trap deployment and the on-farm synthesis of bio-fertilizers to lower input expenditures.
- Promote the establishment of formal cooperative marketing syndicates to aggregate harvests, thereby increasing the collective bargaining power of microenterprises directly against large corporate supermarkets and urban wholesalers.

Declarations

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- **Conflict of Interest**

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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- **Data Availability Statement**

The raw data, statistical outputs and socio-economic datasets generated and analyzed during the current study are stored confidentially to protect the privacy of the rural microenterprise respondents but are available from the corresponding authors upon reasonable, academically justified request.

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