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Research Article

Commercial Farming of High-Value Fruits and Crops: A Baseline-Endline-Control Group Comparative Assessment in Mirsarai, Sitakunda and Hathazari, Chattogram, Bangladesh

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Abstract

The transition from subsistence farming to commercial agriculture is critical for rural poverty alleviation and food security. This study evaluates the impact of the "High Value Fruits and Crops (HVF&C) Varieties Extension and Marketing Sub-Project" on technological adoption, market integration, economic outcomes and nutritional security in Chattogram, Bangladesh. A mixed-methods baseline-endline-control group comparative design was employed. Evaluated parameters included income, agricultural practices, technological uptake and Minimum Dietary Diversity for Women (MDD-W). The intervention was associated with substantial socioeconomic changes among the beneficiaries. Monthly primary income for treatment entrepreneurs increased 14,826.87 ± 9,188.67 BDT at endline, compared to 4,758.14 ± 2,453.26 BDT at baseline and 12,743.06 ± 6,515.96 BDT for the control group. Beneficiaries reported substantial adoption of HVF&C cultivation (91.9%), adopting Good Agricultural Practices (96.9%) and safe agriculture (96.4%). Technology adoption increased with 39.1% of beneficiaries adopting modern irrigation and 77% utilizing mechanized production systems. Market linkages expanded, with 71.75% of beneficiaries securing active marketing channels, significantly mitigating post-harvest losses. Nutritional outcomes were higher among beneficiaries, 61.77% of beneficiary women achieved adequate MDD-W scores (≥ 5 food groups), contrasting sharply with 27.78% in the control group. Furthermore, women's empowerment in financial and agricultural decision making was reported by more than 99% of respondents among beneficiaries. The project was associated with a shift toward market oriented, technology enabled agribusiness microenterprises. By bridging gaps in technical knowledge, financial inclusion and value chain connectivity, the intervention offers a may provide useful evidence for similar interventions for advancing climate smart horticulture and rural nutritional security in South Asia.

Keywords

Agricultural Commercialization, Financial Inclusion, High-Value Fruits and Crops, Market Integration, Technological Adoption

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1. Introduction

The global transformation of agri-food systems has increasingly positioned smallholder agriculture at the nexus of economic development, climate resilience and nutritional security [1]. In South Asia, where the rural economy remains heavily dependent on subsistence farming, transitioning toward commercialized, high-value agriculture is widely recognized as a critical pathway for poverty alleviation [2]. The cultivation of High-Value Fruits and Crops (HVF&C) offers distinct advantages over traditional staple grain production, including higher profit margins, greater potential for value addition and enhanced employment generation across the rural supply chain [3]. However, smallholder market integration is frequently constrained by systemic barriers, including a lack of access to formal credit, inadequate technical extension services, post-harvest infrastructure deficits and vulnerability to climate induced shocks [4].

To navigate these constraints, contemporary agricultural development increasingly emphasizes technological adoption, digital connectivity and multi-actor value-chain collaboration. Climate-smart technologies, including improved irrigation systems, digital advisory tools and precision-oriented farm management practices, can improve resource-use efficiency and strengthen smallholder resilience to environmental and market risks. In Bangladesh, recent studies indicate that agricultural digitalization is gradually expanding through mobile based services, digital information platforms and emerging technology applications, although unequal access to digital infrastructure, skills and services continues to constrain adoption among smallholder farmers [5, 6]. Digital technologies are also becoming increasingly relevant for agricultural market integration and value chain coordination. For example, mobile communication and digital platforms can reduce information asymmetry, facilitate market participation and improve access to financial and advisory services. However, evidence from Bangladesh suggests that farmers' use of digital financial services remains uneven, with limited digital literacy, technological risks and operational constraints restricting the effective use of these services for agricultural transactions, credit and market participation [7].

Emerging technologies such as the Internet of Things (IoT), blockchain based traceability and other digital supply chain systems offer additional opportunities for monitoring farm activities, improving transparency and strengthening coordination between producers and downstream market actors [6, 8]. A recent Bangladesh based study demonstrated the potential of blockchain enabled systems to enhance traceability, transparency and fairer pricing in agri-food value chains [8]. Such technologies may therefore contribute to reducing transaction costs and information asymmetry, particularly in complex horticultural supply chains involving multiple intermediaries. Nevertheless, the empirical evidence on the actual adoption and effectiveness of advanced digital technologies among smallholder farmers remains limited, particularly when such technological adoption is assessed alongside broader outcomes relating to finance, market integration and household welfare [5-8].

Beyond economic metrics, agricultural commercialization exerts a profound influence on household food security and dietary quality. Historically, agricultural policy has demonstrated a preoccupation with staple grains, often overlooking the nutritional imperatives of diverse food systems [9]. Nutrition sensitive agricultural interventions are increasingly advocated to address micronutrient deficiencies, with dietary diversity serving as a proxy for both nutrient adequacy and household economic stability [10]. The Minimum Dietary Diversity for Women (MDD-W) indicator, validated by the Food and Agriculture Organization (FAO), is an internationally standardized metric for assessing the proportion of women consuming a diet rich in essential micronutrients [11]. Evaluating the cross sectional impact of HVF&C commercialization on MDD-W is imperative for understanding how agricultural income translates into human capital development, particularly concerning maternal and child health.

In Bangladesh, the coastal and southeastern regions exhibit significant untapped potential for horticultural diversification, though farmers face compounded challenges of soil degradation, salinity and fragmented market linkages [12]. Addressing these localized constraints, the Rural Microenterprise Transformation Project (RMTP) financed by the Palli Karma-Sahayak Foundation (PKSF), the International Fund for Agricultural Development (IFAD) and the Danish International Development Agency (DANIDA) and implemented by Young Power in Social Action (YPSA) initiated the "High Value Fruit and Crops Varieties Extension and Marketing Sub-Project." Operating in the Chattogram district, this initiative aims to foster robust microenterprises through technological extension, Good Agricultural Practices (GAP) implementation and enhanced financial inclusion.

Recent evidence from Bangladesh has increasingly examined agricultural diversification, market access, and their relationships with household dietary diversity and nutritional outcomes. Alam et al. [13] used nationally representative panel data to demonstrate that agricultural production diversification is positively associated with improved dietary diversity among individual members of farm households in Bangladesh. Similarly, Kabir et al. [14] showed that farm production diversity was positively associated with household dietary diversity and that market accessibility and improved irrigation influenced this relationship. These studies demonstrate the importance of production diversity, market access, and agricultural technology in shaping household and individual dietary outcomes. Recent research has also documented the growing importance of digital financial services and technology-enabled agricultural value chains in improving farmers' access to

markets, finance, credit, insurance, and agricultural services [15, 16]. However, the effective use of these digital services remains constrained by limited digital literacy, operational barriers, and uneven adoption among farmers [16]. These studies provide important evidence on individual components of agricultural transformation; however, most have focused on specific relationships, single outcome domains, or technology specific applications rather than evaluating multiple dimensions of agricultural transformation within a unified intervention framework.

Consequently, an important evidence gap remains regarding integrated evaluations that simultaneously examine technological modernization, digital adoption, financial inclusion, market integration, socioeconomic transformation, and nutritional outcomes within a single intervention framework. In particular, although recent Bangladesh-based studies have examined agricultural diversification and dietary outcomes, farm production diversity, market accessibility, agricultural technology use, digital financial services, and blockchain-enabled value-chain systems, these studies have generally not combined a baseline-endline comparison with a contemporaneous non-intervened control group to assess how a high-value horticultural commercialization intervention influences these interconnected outcomes [13-16]. This study addresses this gap by conducting an integrated comparative evaluation of the High Value Fruits and Crops (HVF&C) intervention among smallholder farmers in Chattogram, Bangladesh. Specifically, the study assesses changes in technological modernization, including climate-smart and selected digital technologies, market integration, financial access, socioeconomic outcomes, and women's dietary diversity, comparing beneficiary outcomes with their 2022 baseline status and with a comparable 2025 non-intervened control cohort.

2. Methodology

2.1. Study Area

The research was conducted in the Chattogram District of southeastern Bangladesh, an area characterized by diverse topography suitable for horticulture but historically constrained by traditional farming paradigms. The treatment (beneficiary) areas comprised Sitakunda Upazila (specifically the unions of Bariyardhala, Sitakunda Sadar, Muradpur, Barbakund, Banshbaria, Bara Kumira, Sonaichari and Bhatiari) and Mirsarai Upazila (Wahedpur, Khaiyachara and Mirsarai). Hathazari Upazila (Fatehpur, 1 no. Chatogram City Corporation and Chikomdondi) was strategically selected as the control area due to its comparable agro-ecological and socio-demographic baseline characteristics, lacking the specific project interventions.

2.2. Research Design, Sampling Strategy and Sample Size

The baseline (2022) and endline (2025) surveys were conducted using independent cross-sectional samples. Therefore, the same households were not tracked longitudinally. The study employed a mixed-methods, experimental research design utilizing a Baseline (2022), Endline (2025) comparative framework, augmented by an Endline Control Group (2025) to isolate project impacts. In Baseline survey (2022) required baseline sample size (n) was mathematically derived using the standard formula for proportions: Primary data were collected from a total 496 number of samples. As per standard proportion (UP: Ultra Poor 10%, TP: Transitional Poor 19%, EP: Entrepreneur Poor 71%) area and poverty wise sample has been taken. To assess the existing value chain for high value fruits and crops of that selected Upazilla 46 numbers of sample were taken from different marketing channel; another 41 numbers of sample were selected from the researchers of different organizations.

In Endline survey (2025) the target population consisted of 6,038 project beneficiaries comprising marginal farmers, micro-entrepreneurs and value chain actors. A stratified cluster sampling technique was applied. The project areas of Mirsarai and Sitakunda were stratified into unions and villages (clusters). Applying Cochran's formula for statistical significance yielded a target of 361 beneficiary households. To satisfy robust evaluation criteria and fulfill project mandates, an additional 20% control group (N=72) was sampled from Hathazari Upazila. Thus, the total quantitative sample size for the endline comparison was N=433.

A baseline survey was not conducted in the control area. Therefore, pre-intervention equivalence between the treatment and control groups could not be statistically verified. The control group was selected based on its agro-ecological and socio-demographic similarity to the intervention areas; however, this study design does not permit definitive causal attribution of observed differences solely to the intervention.

2.3. Data Collection Procedures

Data collection utilized a rigorous framework for both periods. Extensive reviews of regional horticultural marketing channels informed the preparation of diverse, semi-structured questionnaires. These targeted HVF&C production, consumption (MDD-W for females aged 18-45), marketing channels, local value chains, income shifts and institutional support. Authentic data, speeches and documents were cross-referenced with top authorities (e.g., UAO, RARS, HARS, PTCBL, local government). Digital photography was utilized to frame and authenticate different steps during the field investigation. Qualitative data were gathered concurrently until data saturation, utilizing purposive sampling. The endline involved six Focus Group Discussions (FGDs, 10-20 participants), 63 Key Informant Interviews (KIIs) spanning value chain actors and

six In-Depth Interviews (IDIs) with prominent entrepreneurs.

2.4. Nutritional Assessment (MDD-W)

Nutritional outcomes were assessed using the FAO validated Minimum Dietary Diversity for Women (MDD-W) indicator. Dietary recall data (24-hour) were collected for women of reproductive age across all surveyed households. Consumption was categorized into standard food groups. A score of ≥ 5 food groups indicated adequate minimum dietary diversity.

2.5. Statistical Analysis

Collected primary data were digitally encoded into Microsoft Excel 2013 for basic descriptive statistics and the calculation of Standard Deviations (SD). Comparative analyses to measure intervention impacts across the Baseline, Endline Beneficiary and Endline Control cohorts. Qualitative data underwent thematic analysis to triangulate statistical trends.

3. Results

3.1. Overall Baseline-Endline Socio-Demographic Changes

The intervention period observed changes in the socio-demographic and educational profiles of the farming communities (Table 1). At baseline (2022), a significant portion of the beneficiary population faced educational deficits, with 38.90% possessing no formal education. By the 2025 endline, literacy and educational engagement had increased; the illiteracy rate dropped to 29.4%. Female participation increased and youth into the agricultural enterprise sector. Female participation grew from 9.52% at baseline to 16.9% at endline. Crucially, 62.71% of the endline beneficiary cohort fell within the 25-35 years age bracket, compared to only 19.32% in the control group.

Table 1. *Demographic and educational profile of farmers.*

Characteristic	Categories	Baseline Beneficiaries (N=496;%)	Endline Beneficiaries (N=361;%)	Endline Control (N=72;%)
Gender	Male	90.48	83.10	92.56
	Female	9.52	16.90	7.44
Age distribution	< 25 years	15.60	8.64	11.12
	25 - 35 years	38.30	62.71	19.32
	35 - 45 years	25.20	18.50	30.16
	45 and Above	21.00	10.05	39.40
Education level	No formal education / Illiterate	38.90	29.40	29.17
	Primary	25.70	35.30	38.89
	Secondary	29.00	28.90	30.56
	Higher Secondary / Above	6.40	6.40	1.39

Occupational structures diversified significantly (Table 2). While agriculture remained the primary occupation (93.35% for beneficiaries at endline), secondary off-farm livelihoods expanded to build household resilience against agrarian shocks.

Table 2. *Primary and secondary occupational structure.*

Occupation	Categories	Baseline Beneficiaries (%)	Endline Beneficiaries (%)	Endline Control (%)
Main occupation	Farming/Agriculture	87.20	93.35	98.61
	Livestock	-	25.76	36.11
	Business/Trading	3.70	10.80	9.72

Occupation	Categories	Baseline Beneficiaries (%)	Endline Beneficiaries (%)	Endline Control (%)
Secondary occupation	Housewife	-	3.88	-
	Daily Labour	3.70	9.97	6.94
	Handicrafts	12.70	25.48	18.06
	Business	46.80	26.32	30.56
	Day labor	27.70	23.55	27.78
	Others/Service/Remittance	12.80	58.73	47.22

3.2. Income and Economic Outcomes

The transition to HVF&C cultivation was associated with increased income (Table 3). Average monthly primary income for entrepreneurs increased from 4,758.14 ± 2,453.26 BDT at baseline to 14,826.87 ± 9,188.67 BDT at endline. In contrast, the control group's average sat at 12,743.06 ± 6,515.96 BDT. For main occupations, 63.2% of beneficiaries now earn over 10,000 BDT monthly, compared to 54.2% of the control. The divergence in secondary income is also higher, with 67.1% of beneficiaries earning over 5,000 BDT monthly compared to just 25.0% of the control group.

Table 3. Monthly income distribution (Main and Secondary occupations).

Monthly income range (BDT)	Range	Endline Beneficiaries (%)	Endline Control (%)
Income by main occupation	Less than 5,000	7.8	2.8
	5,001 - 10,000	29.0	43.1
	10,001 - 20,000	43.7	43.1
	20,001 - 30,000	12.5	9.7
	30,001 - 50,000	7.0	1.4
Income by secondary occupation	Less than 5,000	32.9	75.0
	5,001 - 10,000	48.9	16.7
	10,001 - 20,000	14.6	6.9

Table 4 explicitly connects this to HVF&C cultivation: 68.3% of beneficiaries experienced post-cultivation income increases exceeding 10%, a growth tier reached by only 36.1% of the control group. Economically, beneficiaries were twice as likely to gain better access to capital (69.9% vs. 33.3%) and nearly three times as likely to increase savings (67.9% vs. 25.0%).

Table 4. Economic impact and income increases post cultivation.

Indicator	Categories	Endline Beneficiaries (%)	Endline Control (%)
Income increase post HVF&C	0 - 10% Increase	31.4	62.5
	11 - 25% Increase	54.2	34.7
	26 - 50% Increase	14.1	1.4

Indicator	Categories	Endline Beneficiaries (%)	Endline Control (%)
Reported economic changes	Better access to capital	69.9	33.3
	Increased savings	67.9	25.0
	Asset creation	39.0	20.8

3.3. Agricultural Production and Technological Adoption

Table 5 shows changes in crop selection and the adoption of farming practices and the adoption of standardized farming practices. While historically heavily reliant on subsistence rice (82.27%) and basic vegetables (70.64%), 91.9% of the endline beneficiary cohort transitioned to high-value fruit cultivation. Among the beneficiaries, 39.1% reported adopting drip or sprinkler irrigation systems (drip/sprinkler), a technology virtually non-existent at baseline and unobserved in the control group.

Table 5. *Cultivation shifts and adoption of irrigation technologies.*

Indicator	Categories	Endline Beneficiaries (%)	Endline Control (%)
Previous cultivation focus	Rice	82.27	75.0
	Vegetables	70.64	62.5
	Fruit Orchard	12.19	8.3
Current adoption of Drip/Sprinkler	No	60.9	100.0
	Yes, Drip	29.2	0.0
	Yes, Sprinkler	5.2	0.0
	Both	4.6	0.0

As shown in Table 6, beneficiaries reported several benefits associated with these technologies. Beneficiaries reported that irrigation modernization directly contributed to reduced water use (30.0%), increased yields (22.5%) and reduced labor costs (21.3%). A proportion of beneficiaries reported using digital technologies, including IoT-based farm management, crowdfunding platforms, and blockchain-related tools to 7-14% of producers, indicating emerging digital technology use among the surveyed producers in rural microenterprises.

Table 6. *Benefits observed from irrigation and high technology adoption.*

Indicator	Categories	Endline Beneficiaries (%)
Benefits of Drip/Sprinkler systems	Reduced water use	30.0
	Increased yield	22.5
	Reduced labor cost	21.3
Adoption of advanced technologies	IoT for farm management	13.0
	Crowd funding Platform	14.4
	Block Chain	7.2

3.4. Input Sourcing and Financial Access

Table 7 illustrates enhanced input sourcing methodologies. Unlike the control group, which relied almost exclusively on localized private nurseries (87.5%), beneficiaries diversified their procurement, heavily utilizing government institutions (42.38%) and online/mobile platforms (9.97%). To assure quality, beneficiaries leveraged formal verification, with 41.0% procuring exclusively from registered institutions.

Table 7. Sources and quality assurance of HVF seeds/saplings.

Indicator	Categories	Endline Beneficiaries (%)	Endline Control (%)
Sources of Seeds/Saplings	From a nursery	69.25	87.5
	Government institution	42.38	11.1
	Private institution	28.81	38.9
	Online/mobile	9.97	0.0
Methods to ensure quality	Visual: healthy saplings	66.2	77.78
	Visual: disease-free	45.2	52.78
	From a registered institution	41.0	22.22

Access to financial support was examined as a factor associated with agricultural commercialization. As outlined in Table 8, 77.1% of beneficiaries received direct financial support from the RMTP via YPSA, while 78.4% accessed external banking support. Conversely, respondents in the control group reported high interest rates (94.3%) and complicated procedures (88.6%) as major barriers to financial access.

Table 8. Financial access and constraints.

Indicator	Categories	Endline Beneficiaries (%)	Endline Control (%)
Received project financial support	Yes	77.1	19.44
Received external bank support	Yes	78.4	52.8
Major constraints to finance	High interest rates	17.73	94.3
	Lack of collateral/guarantee	16.34	77.1
	Complicated procedures	13.57	88.6

3.5. Market Integration and Value Chain Dynamics

Beneficiaries reported lower levels of post-harvest losses than the control group (Table 9). Only 7.5% of beneficiaries reported post-harvest losses exceeding 10%, whereas 43.1% of the control group suffered losses in the 11-25% range. The control group frequently reported infrastructure-related factors to infrastructural deficits lack of advanced harvesting tech (94.4%) and missing storage (84.7%) complaints that were reduced to below 40% for beneficiaries through targeted project interventions.

Table 9. Biggest challenges in HVF&C cultivation and post-harvest losses.

Indicator	Categories	Endline Beneficiaries (%)	Endline Control (%)
Biggest cultivation challenges	Lack of technical knowledge	44.88	-
	Lack of access to finance	41.83	-
Estimated post-harvest loss	Less than 5%	42.8	16.7
	5 - 10%	49.1	40.3
	11 - 25%	7.5	43.1
Reasons for post-harvest spoilage	Lack of fruit storage facilities	39.1	84.7
	Lack of processing facilities	37.1	77.8
	Lack of advanced harvesting tech	31.6	94.4

Table 10. Value chain actor insights (Endline beneficiary areas).

Actor and indicator	Findings (Beneficiary areas)
HVF large producers (n=5)	
Monthly income	Mean: 79.6k BDT
Adopted climate adaptive tech and fruit bagging	100.0%
Primary constraint	High interest rates / Collateral (75.0%)
Agro machinery sellers (n=4)	
Revenue from HVF farmers	50.0% derive 61-80% of revenue from HVF
Business revenue change	75.0% reported moderate to significant increase
Local fruit collectors (n=2)	
Technology adoption	100% use plastic crates and mobile phones for pricing
Super shops (n=4)	
HVF demand change	75.0% reported significant increase
Daily sales volume	100% sell 26-50 kg daily
Transport agencies (n=4)	
Quality management	100% use proper packaging, timely transport, careful loading
Spoilage rate change	75.0% reported decrease in spoilage rates

Table 10 confirms The findings suggest that changes associated with commercialization extended across several stages of the value chain. Large producers are universally adopting quality enhancing technologies (fruit bagging) and climate-adaptive methods. Agro machinery sellers and Super Shops report reported revenue and demand increases associated with the HVF&C sector. Transport agencies are implementing quality controls that correlate with the reduced post-harvest losses observed among producers.

3.6. Nutritional Outcomes (MDD-W) and Women's Empowerment

Nutritional outcomes were assessed using the MDD-W indicator, measured via MDD-W. At endline, 61.77% of beneficiary women achieved an adequate MDD-W score (consuming ≥ 5 food groups), maintaining the high baseline standard (91.36%). This differed from the control group, where 77.8% of women consumed inadequately diverse diets (<5 food groups). The high MDD-W achievement among beneficiaries is driven by 100% reported consumption of grains, pulses and

fats/seeds, alongside 99.72% reported consumption of meat/poultry/fish. Compared to baseline, protein intake surged. Conversely, the control group exhibited lower dietary diversity, heavily reliant on grains, with pulse consumption at only 34.72% and fats at 25.00%.

The findings indicated changes in women's participation in financial and agricultural decision-making in gender empowerment (Table 11). Among endline beneficiaries, 99.45% of women reported increased involvement in financial decision-making (42.98% noting significant increases). Similarly, agricultural decision-making power increased for 99.21% of beneficiary women, compared with the levels reported in the control group.

Table 11. Women's involvement in decision making.

Indicator	Changes	Endline Beneficiary (%)	Endline Control (%)
Financial decision making	Significantly increased	42.98	13.89
	Somewhat increased	56.47	68.05
	Not at all	0.55	18.06
Agricultural decisions	Significantly increased	48.28	26.39
	Somewhat increased	50.93	70.83
	Not at all	0.80	2.78

3.7. Comprehensive Logframe Indicator Assessment

To assess changes across the project logframe indicators, Table 12 presents a comprehensive cross-sectional matrix of 24 core project logframe indicators, showing higher values for several indicators among the endline treatment group against both their own 2022 baseline and the 2025 control parameters. The adoption of Safe Agriculture (96.40% vs. 41.67% control), GAP (96.9% vs. 23.7% control) and overall market linkage (71.75% vs. 30.56% control) indicate substantial differences between the treatment and control groups.

Table 12. Comprehensive logframe performance indicators (Baseline vs. Endline Treatment vs. Endline Control).

Performance Indicator	Baseline	Endline Treatment	Endline Control
Average primary monthly income (BDT)	4,758.14 ± 2,453.26	14,826.87 ± 9,188.67	6,743.06 ± 3,515.96
Intake of ≥ 5 nutritious food items	23.61%	61.77%	27.78%
Safe agriculture adoption (IPM, Eco-farming)	29.24%	96.40%	41.67%
Average secondary monthly income (BDT)	3,133.56 ± 1,841.73	7,535 ± 5,172	4,513.89 ± 4,271.57
Entrepreneurs reporting structural profit growth	<10%	65.66%	29.17%
Practice of Good Agricultural Practices (GAP)	<25%	96.90%	23.70%
Utilization of active marketing linkages	~28.00%	71.75%	30.56%
Availability/intake of necessary HVF&C inputs	~23.18%	54.29%	19.44%
Received agro-machinery consultancy	<10%	~35.00%	<10%
Demonstrating knowledge of HVF&C cultivation	<10%	100.00%	<20%
Execution of formal supplier/nursery agreements	<10%	43.68%	10.33%
Increase in quality seedling production capacity	--	~35%	<10%
Timely access to inputs/services via centers	--	~25%	<10%
Increased access to machinery via dealers	--	~20%	<10%

Performance Indicator	Baseline	Endline Treatment	Endline Control
Received formal HVF&C cultivation training	<10%	~100%	<20%
Nurseries with established mother stock	0	4	0
Target audience reached via online marketing	<5%	15.24%	8.34%
Planned demonstration plots established	0	~10%	0
Planned Memoranda of Understanding executed	0	~10%	0
Farmers collecting seed/saplings from govt.	<10%	52.00%	11.10%
Adopting mechanized production/traceability	<20%	~77.00%	<30%
Attending Production and Sales Meetings (PSPMs)	<5%	71.40%	<10%
Attending organized field day events	<10%	94.40%	2.80%
Upgraded/installed modern irrigation systems	Negligible	39.10%	Very Low

4. Discussion

The empirical findings from the Baseline-Endline-Control comparison are consistent with the project intervention as a was associated with changes in for rural agricultural transformation in Chattogram. The increase in primary monthly income (from 4,758.14 ±2,453.26 BDT to 14,826.87 ±9,188.67 BDT) and the increase in the proportion of 91.9% of the beneficiary cohort toward high-value fruit cultivation confirm the theoretical frameworks posited by Birthal *et al.* [17], which argue that crop diversification toward non-staple, high-value commodities is a prerequisite for liberating smallholders from the poverty trap of subsistence farming. The control group's lower observed values underscores that mere proximity to urban centers is insufficient; structural interventions, specifically targeted financial inclusion (77.1% YPSA support) and technical capacitation (96.9% GAP adoption), are required to overcome the capital and knowledge constraints highlighted by Barrett [4].

Technological modernization was a an important component of this transformation. The adoption of modern irrigation (drip and sprinkler systems) by nearly 40% of beneficiaries was associated with reduced the climate induced vulnerabilities characteristic of coastal agriculture. As supported by FAO [18] and Arslan *et al.* [19], climate smart agricultural tools not only optimize water use (30% reduction) but simultaneously boost yields (22.5% increase) and labor efficiency. Notably, the project's introduction of emerging digital platforms (IoT, Crowd funding, Block chain) to 7-14% of the cohort represents a nascent but pivotal step toward digitalizing rural microenterprises, addressing the information asymmetry identified by Jack [20] as a primary barrier to market efficiency.

The integration of producers into functional, multi actor value chains decisively mitigated post-harvest losses, a chronic vulnerability in South Asian supply chains [21]. By facilitating formal marketing agreements (43.68% for beneficiaries vs. 10.33% control) and promoting online/mobile procurement, the project may have provided additional marketing options for farmers. The systemic upgrades reported by large collectors, super shops and transport agencies such as universal adoption of plastic crates and active quality management demonstrate that smallholder commercialization induces positive spillover effects, upgrading the entire meso-level agrifood ecosystem [22]. However, the persistence of constraints such as high interest rates and the lack of localized cold storage indicates that while farm level efficiency has peaked, macro-level infrastructural investments remain necessary.

Crucially, the economic dividends of commercialization were accompanied by higher MDD-W adequacy and gender empowerment. The maintenance of high MDD-W adequacy (61.77%) among beneficiary women, juxtaposed against the severe dietary monotony of the control group (77.8% inadequate), illustrates the potential contribution of nutrition sensitive agricultural commercialization [12]. The universal intake of proteins and micronutrient rich vegetables directly correlates with the diversified income portfolios that allowed households to purchase non-farm foods. Furthermore, the near universal inclusion of women in financial and agricultural decision making (>99%) supports the findings of Sraboni *et al.* [23], affirming that inclusive value chain development not only increases household wealth but was associated with increased participation in household decision making, fostering sustainable community resilience.

5. Study Limitations

Several limitations should be considered when interpreting these findings. First, much of the information, including income, agricultural practices, financial outcomes, post-harvest losses and decision-making, was self-reported and may therefore be affected by recall and social desirability bias. Second,

although the control area was selected for its comparable agro-ecological and socio-demographic characteristics and absence of the intervention, it was not randomly allocated. Thus, unobserved differences between beneficiary and control areas may have influenced the results. Third, the baseline and endline surveys represent repeated cross sectional assessments rather than confirmed longitudinal tracking of the same respondents; differences in sample composition may therefore have contributed to observed changes. Finally, because the study was conducted in selected upazilas of Chattogram, Bangladesh, its findings should be generalized cautiously to other contexts. Future studies should use longitudinal tracking and rigorously matched or randomized comparison groups.

6. Conclusion

The comparative evaluation of the High Value Fruits and Crops project indicates that targeted interventions in technological extension, financial inclusion and value chain integration may support the transition of farmers from subsistence to profitable commercial agribusinesses. Over the implementation period, beneficiaries achieved increases in primary and secondary income, accompanied by a high reported adoption of Good Agricultural Practices (96.9%) and a significant uptake of climate-smart irrigation systems. By circumventing traditional market bottlenecks through formalized multi actor linkages, post-harvest losses were was lower among beneficiaries. In addition, these economic gains translated directly into robust nutritional security, with 61.77% of beneficiary women achieving adequate dietary diversity, alongside increased participation in intra household gender empowerment. To ensure the long term sustainability of these outcomes, future policy frameworks must prioritize the expansion of decentralized cold-storage infrastructure and the development of agriculture sensitive, low interest credit products. Ultimately, this intervention serves as a may offer lessons for the design of similar interventions for achieving the Sustainable Development Goals (SDGs) of zero hunger, gender equality and sustainable economic growth in developing agrarian economies.

Abbreviations

BDT	Bangladesh Taka
CSA	Climate Smart Agriculture
DANIDA	Danish International Development Agency
EP	Entrepreneur Poor
FAO	Food and Agriculture Organization
FGDs	Focus Group Discussions
GAP	Good Agricultural Practices
HARS	Horticultural Agriculture Research Station
HVF&C	High Value Fruits and Crops
IDIs	In-Depth Interviews
IFAD	International Fund for Agricultural Development
IoT	Internet of Things
KIIs	Key Informant Interviews
MDD-W	Minimum Dietary Diversity for Women
PKSF	Palli Karma-Sahayak Foundation
PTCBL	Plant Tissue Culture and Biotechnology Laboratory
RARS	Regional Agricultural Research Station
RMTP	Rural Microenterprise Transformation Project
SD	Standard Deviations
SDGs	Sustainable Development Goals
TP	Transitional Poor
UAO	Upazila Agriculture Officer
UP	Ultra Poor
YPSA	Young Power in Social Action

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Author Contributions

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Data Availability Statement

The raw quantitative datasets, interview transcripts and statistical analytical outputs supporting the conclusions of this manuscript are retained by the executing agency (YPSA) and will be made available by the corresponding author upon reasonable academic request, subject to privacy restrictions.

Conflicts of Interest

The authors declare no conflicts of interest.

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