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Impact of high-value fruits and crops cultivation on household dietary diversity: An endline comparative assessment of beneficiary and control groups in Mirsarai, Sitakunda and Hathazari Upazilas of Chattogram, Bangladesh

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Abstract

The transition from subsistence farming to commercial high-value agriculture is a critical pathway for improving rural livelihoods and nutritional outcomes in developing economies. This study evaluates the impact of the High Value Fruits and Crops (HVF&C) Varieties Extension and Marketing Sub-Project on Household Dietary Diversity (HDD), food security and economic empowerment in Chattogram, Bangladesh utilizing a cross sectional comparative endline assessment design. Empirical findings indicate a profound transformation in agricultural microenterprises. Compared to the control group, beneficiaries demonstrated significantly higher adoption of climate adaptive technologies (93.9% vs. 5.6%), greater access to customized financial support (95.3% vs. 23.6%) and improved integration into direct-to-consumer and institutional market channels (90.6% vs. 5.6%). Consequently, 82.8% of beneficiaries reported increased agricultural production and 62.3% reported increased profit, contrasting sharply with negligible gains in the control cohort. Crucially, these economic and technological pathways directly translated into nutritional security; 82.3% of beneficiary households achieved improved food quality and dietary diversity and 80.6% reported enhanced food availability, compared to just 5.6% and 2.8% in the control group, respectively. The study concludes that holistic interventions combining High-Value Fruits and Crops extension, market linkages and inclusive financial services successfully establish resilient agricultural microenterprises, driving both regional economic growth and sustainable improvements in household dietary diversity.

Keywords: Food security, high-value fruits and crops, household dietary diversity, market linkages, rural transformation

1. Introduction

The structural transformation of rural agricultural systems is fundamental to alleviating poverty and combating malnutrition in South Asia (Asaduzzaman, 2010; Reardon and Timmer, 2012) [5, 31]. Historically, agricultural interventions in Bangladesh have predominantly focused on staple cereal production to achieve caloric self-sufficiency (Pingali, 2015) [29]. However, as rural economies evolve, there is a recognized imperative to transition toward high-value agriculture specifically fruits, vegetables and commercial crops. These horticultural shifts offer superior income-generating potential, transform rural livelihoods and provide profound nutritional benefits (Weinberger and Lumpkin, 2007; Ali, 2008) [36, 3]. High-Value Fruits and Crops present a unique opportunity to integrate marginalized smallholder farmers into expanding domestic and global value chains, thereby catalyzing rural microenterprise development and mitigating rural poverty (Rahman, 2017; Cock, 2020) [30, 9].

The relationship between agricultural commercialization, income growth and household nutrition is complex and heavily mediated by market access, technology adoption and

financial inclusion (Gómez and Ricketts, 2013; Awotide *et al.*, 2016; Kuma *et al.*, 2019) ^[11, 7, 22]. Increased agricultural income serves as the primary economic pathway to improved food security, enabling households to enhance their purchasing capacity and diversify their diets beyond staple grains (Parvin *et al.*, 2014; Pingali, 2015) ^[28, 29]. Dietary diversity, particularly Household Dietary Diversity (HDD), acts as a robust proxy for household food access and the micronutrient adequacy of the diet (Arimond and Ruel, 2004; FAO, 2011; Kennedy *et al.*, 2011) ^[4, 10, 21]. Despite the known benefits of dietary diversification, rural smallholders in coastal and disaster-prone regions like Chattogram face systemic barriers. These include fragmented market linkages, limited access to climate-resilient technologies and severe financing constraints (Ahmed *et al.*, 2025; Hassan *et al.*, 2010) ^[1, 13]. Furthermore, post-harvest losses and inefficient supply chains consistently erode potential profit margins for perishable high-value commodities (Kaminski and Christiaensen, 2014; LightCastle Partners, 2023) ^[19, 23].

Young Power in Social Action (YPSA) initiated the HVF&C Varieties Extension and Marketing project aimed to optimize production practices, promote Good Agricultural Practices (GAP) and establish robust backward and forward market linkages for smallholder farmers in Sitakunda and Mirsarai Upazilas. Central to this intervention is the hypothesis that targeted capacity building, financial support and market integration not only drive economic profitability but also empower women in agricultural decision making, ultimately leading to elevated HDD (Ruel and Alderman, 2013; Sraboni *et al.*, 2014; IFAD, 2019) ^[32, 14, 18].

While broad literature supports the efficacy of value chain interventions (Torero, 2011; Trienekens, 2011) ^[34, 35], there remains a critical research gap regarding the localized, empirical impacts of such integrated microenterprise models on direct dietary outcomes in southeastern Bangladesh. This manuscript aims to bridge this gap by presenting a comprehensive comparative analysis between the RMTP endline beneficiary cohort and a non-intervention control group. Specifically, the study evaluates how shifts in agricultural decision making, land utilization, technological adoption, market channels and financial access function as direct pathways to achieving superior food security and HDD.

2. Methodology

2.1 Study area and design

The research employed a cross sectional comparative endline evaluation design to assess the outcomes of the HVF&C sub-project was conducted in the Chattogram district of Bangladesh. The beneficiary group was sampled from Sitakunda Upazila (unions including Bariyardhala, Sitakunda Sadar, Muradpur, Barbakund, Banshbaria, Bara Kumira, Sonaichari and Bhatari) and Mirsarai Upazila (unions including Wahedpur, Khaiyachara and Mirsarai Municipality). The control group, mirroring the demographic and geographic characteristics of the

beneficiary area but without project intervention, was selected from Hathazari Upazila (Fatehpur, Chattogram City Corporation Ward 1 and Chikondondi).

2.2 Sampling strategy and sample size

A mixed methods approach was utilized, though this manuscript focuses exclusively on the robust quantitative dataset. Statistical sampling was conducted using Cochran's formula to ensure a high confidence level and statistical significance. From a total project population of 6,038 households, a definitive quantitative sample size of N=433 was established. This cohort was strictly stratified into n=361 Beneficiary participants and a 20% proportional control group comprising n=72 non-beneficiary households.

2.3 Data collection and measurement indicators

Data were collected *via* semi structured, digitized questionnaires through direct interviews. The core measurement indicators assessed structural changes across seven domains: i. empowerment and decision making; ii. livelihood and income profiling; iii. land use and cropping patterns; iv. technology and climate adaptive practices; v. training and capacity building; vi. market linkages and post-harvest management and vii. financial inclusion.

To evaluate nutritional outcomes, the study utilized self-reported indicators of household food security, food availability and food quality/diversity as proxies for HDD, for measuring dietary diversity at the household level (Kennedy *et al.*, 2011; FAO, 2011) ^[21, 10].

2.4 Data analysis

Quantitative data were processed and analyzed using SPSS and Microsoft Excel. Descriptive statistics, specifically frequencies and percentages, were calculated to systematically compare the performance and outcomes of the Beneficiary (n=361) and Control (n=72) groups.

3. Results

The empirical findings are presented through a comprehensive comparative analysis of the Beneficiary and Control cohorts. The tables and accompanying analyses highlight the major quantitative differences driven by the RMTP intervention.

3.1 Household financial and agricultural decision making:

Table 1 demonstrates a substantial shift in intra-household empowerment and decision-making. Among beneficiaries, 89.5% reported a significant increase in their involvement in household financial decisions compared with before the project. In contrast, 58.3% of the control group reported no involvement, while only 6.9% reported significant involvement. A similar pattern was observed in agricultural planning, with 88.4% of beneficiaries significantly involved in agricultural decisions, compared with 43.1% of control households completely excluded and 51.4% reporting "somewhat" involvement.

Table 1: Household financial and agricultural decision making

Query	Category	Beneficiary (Count)	% of n=361	Control (Count)	% of n=72
Involved in household financial decision making compared to before the project	Significantly	323	89.5	5	6.9
	Somewhat	38	10.5	25	34.7

	Not at all	---	---	42	58.3
Involved in decisions regarding agricultural activities	Significantly	319	88.4	4	5.6
	Somewhat	41	11.4	37	51.4
	Not at all	1	0.3	31	43.1

3.2 Livelihood, occupation and household income dynamics: Farming remains the primary occupation for both groups, accounting for 86.7% of beneficiaries and 65.3% of controls; however, income stratification indicates a notable economic improvement among beneficiaries (Table 2). Among them, 51.5% moved into the BDT 10,001-20,000 monthly income, while 21.3% reached BDT

20,001-30,000. In contrast, 61.1% of controls remained in the lower BDT 5,001-10,000 tier. Secondary income generation favored beneficiaries, with 36.6% reporting BDT 20,001-40,000 versus 13.9% of controls. Notably, 98.3% reported positive changes in total household income, compared with 9.7% of controls.

Table 2: Main occupation, household income and livelihood changes

Query	Category	Beneficiary (Count)	% of n=361	Control (Count)	% of n=72
Respondent or head of the household main occupation	Farming/Agriculture	313	86.7	47	65.3
	Livestock	7	1.9	6	8.3
	Business/Trading	29	8.0	6	8.3
	Service/Job	3	0.8	1	1.4
	Daily labor	3	0.8	9	12.5
	Handicrafts	3	0.8	---	---
	Others	3	0.8	3	4.2
Monthly income by main occupation	Less than 5,000 BDT	23	6.4	11	15.3
	5,001 - 10,000 BDT	33	9.1	44	61.1
	10,001 - 20,000 BDT	186	51.5	16	22.2
	20,001 - 30,000 BDT	77	21.3	1	1.4
	30,001 - 50,000 BDT	32	8.9	---	---
	Above 50,000 BDT	10	2.8	---	---
Yearly income generated by another household member	Less than 10,000 BDT	48	13.3	30	41.7
	10,001 - 20,000 BDT	147	40.7	31	43.1
	20,001 - 40,000 BDT	132	36.6	10	13.9
	40,001 - 70,000 BDT	34	9.4	1	1.4
Household income changed due to the project	Yes	355	98.3	7	9.7
	No	6	1.7	65	90.3

3.3 Cultivable and leased land utilization and profitability: Beneficiaries demonstrated superior land access, crop diversification, and profitability on both owned and leased land (Tables 3 and 4). Almost all beneficiaries (98.6%) cultivated their own land, mainly using 11-30 decimal plots (49.3%), while controls primarily operated on smaller 1-10 decimal plots (44.4%). Beneficiaries diversified beyond cereals, cultivating vegetables (78.1%), pulses (74.8%), high-value fruits (46.3%), and spices/medicinal crops (12.5%). In contrast, controls

cultivated fruits (2.8%), while pulses and spices were absent (0.0%). Consequently, 46.5% of beneficiaries achieved quarterly gross profits of BDT 15,001-40,000 on own land, compared with 2.8% of controls. Similarly, 85.0% of beneficiaries leased land versus 59.7% of controls, favoring vegetables (68.4%) and high-value fruits (56.5%). Thus, 49.3% earned BDT 15,001-40,000 quarterly, while losses affected 18.1% of controls compared with 3.3% of beneficiaries.

Table 3: Ownership of cultivable land, cropping patterns and quarterly gross profit

Query	Category	Beneficiary (Count)	% of n=361	Control (Count)	% of n=72
Have any own cultivable land	Yes	356	98.6	38	52.8
	No	5	1.4	34	47.2
Total area (in decimal)	1-10 decimal	69	19.1	32	44.4
	11-30 decimal	178	49.3	6	8.3
	31-60 decimal	88	24.4	---	---
	61-100 decimal	20	5.5	---	---
	101 to above decimal	1	0.3	---	---
Cultivated Main Crops	Rice/ Maize/ Wheat / Jute	313	86.7	35	48.6
	Pulses	270	74.8	0	0.0
	Vegetables	282	78.1	23	31.9
	High-Value Fruits	167	46.3	2	2.8
	Spices/ Medicinal/ Aromatic	45	12.5	0	0.0
	Other Crops	166	46.0	0	0.0

Quarterly Gross profit (BDT)	Loss (< 0)	23	6.4	9	12.5
	0-15,000	153	42.4	27	37.5
	15,001-40,000	168	46.5	2	2.8
	40,001-1,00,000	12	3.3	---	---

Table 4: Leased cultivable land, cropping patterns and quarterly gross profit

Query	Category	Beneficiary (Count)	% of n=361	Control (Count)	% of n=72
Have any leased cultivable land	Yes	307	85.0	43	59.7
	No	54	15.0	29	40.3
Total area (in decimal)	1–50 decimal	163	45.2	38	52.8
	51–100 decimal	93	25.8	5	6.9
	101–200 decimal	42	11.6	—	—
	201–500 decimal	9	2.5	—	—
Cultivated Main Crops	Rice/Maize/Wheat/Jute	223	61.8	37	51.4
	Pulses	196	54.3	8	11.1
	Vegetables	247	68.4	41	56.9
	High-Value Fruits	204	56.5	5	6.9
	Spices/Medicinal/Aromatic	71	19.7	2	2.8
	Other Crops	158	43.8	3	4.2
Quarterly Gross profit (BDT)	Loss (< 0)	12	3.3	13	18.1
	0–15,000	95	26.3	19	26.4
	15,001–40,000	178	49.3	11	15.3
	40,001–1,00,000	22	6.1	—	—

3.4 Climate adaptive practices and agricultural technology: Table 5 highlights sustainable agronomy among beneficiaries. An overwhelming 93.9% possessed knowledge of and followed climate-adaptive technologies, compared to 5.6% of controls. Beneficiaries widely used bio-pesticides (94.5%), bio-fertilizers (89.2%), fruit bags (40.7%), and pheromone traps (40.4%), considering these inputs highly available (95.8%) and cost-effective (89.2%).

Consequently, 82.3% reported increased crop yields and 97.2% noted positive environmental impacts. Additionally, 93.4% adopted new agricultural technologies and 46.8% used digital/ICT tools. Despite high costs (83.1%) and limited technical knowledge (73.4%), 97.0% affirmed that the RMTP project made these technologies accessible and cost-effective.

Table 5: Climate adaptive practices and agricultural technology adoption

Query	Category	Beneficiary (Count)	% of n=361	Control (Count)	% of n=72
Knowledge/following climate adaptive tech	Have knowledge; I follow	339	93.9	4	5.6
	Have knowledge; I don't follow	15	4.2	12	16.7
	Have no knowledge	7	1.9	56	77.8
Specific agronomic practices	Bio Pesticide	341	94.5	10	13.9
	Bio Fertilizer	322	89.2	1	1.4
	Pheromone Trap	146	40.4	1	1.4
	Fruits Bag	147	40.7	3	4.2
	Others	203	56.2	44	61.1
Availability of bio inputs at nearby market	Yes	346	95.8	3	4.2
	No	14	3.9	69	95.8
Cost-effective compared to chemical inputs	Cost effective	322	89.2	3	4.2
	Costly	39	10.8	69	95.8
Impact in production cost or yield	Increased production cost	198	54.8	1	1.4
	Decreased production cost	144	39.9	1	1.4
	Increased yield	297	82.3	2	2.8
	Decreased yield	10	2.8	---	---
	No significant change	6	1.7	10	13.9
Perceive the overall environmental impact	Positive	351	97.2	2	2.8
	Negative	4	1.1	29	40.3
	No change	4	1.1	36	50.0
Adopted/improved technology via project	Farming/Agricultural technology	337	93.4	2	2.8
	Processing/Manufacturing tech	270	74.8	0	0.0
	Digital/ICT technology	169	46.8	0	0.0
	Others	186	51.5	1	1.4
Impact of this technology	Increased productivity	313	86.7	----	----

	Reduced costs	220	60.9	----	----
	Improved product quality	249	69.0	----	----
	Easier management	157	43.5	----	----
	Others	170	47.1	----	----
Challenges while adopting technologies	High cost of technology	300	83.1	69	95.8
	Lack of technical knowledge/training	265	73.4	61	84.7
	Difficulty in maintenance/repairs	219	60.7	23	31.9
	Limited access to resources or inputs	179	49.6	38	52.8
	Resistance from staff/workers	80	22.2	31	43.1
	Other	182	50.4	43	59.7
Project made tech accessible/cost-effective	Yes	350	97.0	----	----
	No	10	2.8	----	----

3.5 Institutional capacity development and training

Table 6 demonstrates strong institutional capacity building. Nearly all beneficiaries (97.8%) received specialized training, compared with 88.9% of controls receiving none. Training was mainly delivered by RMTP/YPSA staff (91.1%), NGOs (51.0%) and government agricultural departments (28.5%). The practical curriculum covered

organic fertilizer use (92.2%), marketing and sales (68.4%), composting (55.4%), climate-resilient practices (46.3%) and safe storage (45.4%). Consequently, beneficiaries reported substantial improvements in technical skills (84.8%), business and management skills (74.8%) and financial management (61.8%), while these improvements were absent in the control group.

Table 6: Training, certification and capacity development

Query	Category	Beneficiary (Count)	% of n=361	Control (Count)	% of n=72
Received training (technical/managerial)	Yes	353	97.8%	8	11.1%
	No	4	1.1	64	88.9
Provided the training organization	RMTP/YPSA Staff	329	91.1	1	1.4
	Research or academic institution	34	9.4	0	0.0
	Government agricultural dept.	103	28.5	3	4.2
	NGO / Development organization	184	51.0	7	9.7
	Private company/Fertilizer supplier	47	13.0	2	2.8
	Farmer cooperatives/Associations	45	12.5	1	1.4
	Others	97	26.9	0	0.0
Specify the topics covered in training	Proper use of organic fertilizers	333	92.2	8	11.1
	Benefits for crops/environment	263	72.9	1	1.4
	Marketing and sales techniques	247	68.4	1	1.4
	Safe storage and handling	164	45.4	3	4.2
	Composting/bio-fertilizer prod	200	55.4	1	1.4
	Cost-benefit and record keeping	95	26.3	4	5.6
	Climate-resilient practices	167	46.3	0	0.0
	Digital/online marketing	103	28.5	1	1.4
	Others	180	49.9	3	4.2
How training improved capacity	Improved technical skills	306	84.8	6	8.3
	Improved skills	270	74.8	5	6.9
	Improved financial management	223	61.8	0	0.0
	Improved knowledge on quality	209	57.9	3	4.2
	Improved ability to find buyers	127	35.2	0	0.0
	Other	191	52.9	1	1.4

3.6 Market linkages, sales channels and post-harvest handling: Integration into modernized value chains was a major success (Tables 7 and 8). An impressive 90.6% of beneficiaries changed their sales channels due to the project, gaining access to export and city markets (87.0%), direct consumer sales (68.4%), farmer cooperatives (53.2%), and mobile apps/technologies (54.3%). Product promotion relied on personal communication (82.3%) and customer orchard visits (64.0%). Moreover, 58.7% partnered with large

institutional buyers (Big Arot), while 46.5% engaged in contract farming. Post-harvest handling also improved. While 94.4% of controls sold fruits the same day, beneficiaries used normal-temperature store rooms (42.1%) and local cold storage (39.3%). Packaging sales to Arot reached 97.0%, using plastic sacks (76.2%), polythene sheets (70.4%), and jute bags (54.8%). Consequently, 60.9% kept transport/packaging damage below 5%, while 23.8% reported zero loss.

Table 7: Sales channels, marketing practices and market linkages

Query	Category	Beneficiary (Count)	% of n=361	Control (Count)	% of n=72
Sales channels changed due to project	Yes	327	90.6	4	5.6
	No	5	1.4	60	83.3
	Somewhat	29	8.0	2	2.8
How channels or methods changed	Increased access to new markets	314	87.0	4	5.6
	Improved price realization	225	62.3	1	1.4
	Sell directly to consumers	247	68.4	0	0.0
	Selling through cooperatives	192	53.2	0	0.0
	Using new technologies	196	54.3	0	0.0
	Improved negotiation skills	139	38.5	0	0.0
	Diversification of sales channels	88	24.4	0	0.0
Supports linked to project interventions	Training	290	80.3	9	12.5
	Finance	205	56.8	1	1.4
	Packaging	210	58.2	0	0.0
	Transport	186	51.5	0	0.0
	Others	188	52.1	18	25.0
Promotion of product sale	Customer visits at orchard	231	64.0	9	12.5
	Personal communication	297	82.3	21	29.2
	Online promotion	184	51.0	4	5.6
	Others	211	58.4	24	33.3
Project improved promotional activities	Yes	339	93.9	0	0.0
	No	20	5.5	100	0.0
Partnership with any buyer for sales	Big Arot	212	58.7	1	1.4
	Contract farming	168	46.5	7	9.7
	Processing company	122	33.8	0	0.0
	Others	200	55.4	64	88.9

Table 8: Post harvest handling, packaging, preservation and product losses

Query	Category	Beneficiary (Count)	% of n=361	Control (Count)	% of n=72
Preservation Methods of fruits	Store room (normal temp)	152	42.1%	3	4.2
	Local cold storage	142	39.3	1	1.4
	Don't store, sell same day	65	18.0	68	94.4
Packaging during sales to Arot	Yes	350	97.0	7	9.72
	No	8	2.2	65	90.28
Types of used packaging	Jute bags/sacks	198	54.8	2	2.8
	Plastic sacks/bags	275	76.2	2	2.8
	Wooden crates	75	20.8	0	0.0
	Bamboo baskets	141	39.1	1	1.4
	Polythene sheets	254	70.4	1	1.4
	No specific packaging	58	16.1	39	54.2
	Other	78	21.6	1	1.4
Face any product damage	No loss	86	23.8	1	1.4
	Up to 5% of total value	220	60.9	26	36.1
	5% - 10% of total value	40	11.1	8	11.1
	More than 10% of total value	5	1.4	3	4.2
	Don't know/Can't calculate	6	1.7	27	37.5

3.7 Access to financial support and constraints

Financial inclusion increased substantially through the intervention (Table 9). Overall, 95.3% of beneficiaries accessed financial support, mainly through MFIs/NGOs (65.1%) and cooperatives (26.3%). Within YPSA, beneficiaries used Buniyad (33.8%), Sufal (26.6%) and

Jagoran (24.7%). Funds supported input purchases (52.1%), working capital (50.4%) and equipment/technology (45.4%). Key constraints included high interest rates (66.8%), lack of collateral (52.4%) and complex paperwork (46.8%). In contrast, 76.4% of controls remained excluded from formal financial support.

Table 9: Access to financial support, sources of finance and financing constraints

Query	Category	Beneficiary (Count)	% of n=361	Control (Count)	% of n=72
Received financial support/loan	Yes	344	95.3	17	23.6
	No	17	4.7	55	76.4

Source of the loan/finance	Bank	86	23.8	5	6.9
	MFI/ NGO	235	65.1	17	23.6
	Cooperative/Association	95	26.3	10	13.9
	Friends/Relatives	91	25.2	9	12.5
	Others	92	25.5	0	0.0
YPSA program received loan	Sufal	96	26.6	----	----
	Buniyad	122	33.8	----	----
	Jagoran	89	24.7	----	----
	OBA	17	4.7	----	----
Purpose of access the loan/finance	Purchase inputs	188	52.1	8	11.1
	Expand orchard/land	159	44.0	1	1.4
	Purchase of equipment/tech.	164	45.4	2	2.8
	Working capital	182	50.4	21	29.2
	Household consumption	102	28.3	9	12.5
	Others	158	43.8	4	5.6
Constraints in accessing finance	High interest rates	241	66.8	29	40.3
	Lack of collateral/guarantee	189	52.4	6	8.3
	Complicated paperwork	169	46.8	1	1.4
	Limited access to institutions	155	42.9	2	2.8
	Insufficient loan amount	141	39.1	1	1.4
	Delayed loan approval	88	24.4	1	1.4
	No constraints	42	11.6	5	6.9

3.8 Project outcomes, dietary diversity and demographic inclusivity: Table 10 highlights the project's economic and nutritional outcomes. Among beneficiaries, 82.8% reported increased production and 62.3% increased profit/income. Improved purchasing capacity (59.6%) contributed to higher food quality and dietary diversity (82.3%) and increased food availability (80.6%), while 70.8% of controls reported

no food security improvement. Female participation was high among 53.7% of beneficiaries versus 0.0% of controls, with 63.4% of participants aged 18-25. Beneficiaries recommended improved finance access (83.7%), modern transport logistics (68.1%), and greater women/youth inclusion (71.2%).

Table 10: Project outcomes, food security, women's participation and sustainability

Query	Category	Beneficiary (Count)	% of n=361	Control (Count)	% of n=72
Changes in production/sales/profit	Increased production	299	82.8%	3	4.2
	Increased sales	235	65.1	1	1.4
	Increased profit/income	225	62.3	0	0.0
	Better product quality	197	54.6	0	0.0
	Improved market access	173	47.9	1	1.4
	No significant change	25	6.9	48	66.7
	Others	167	46.3	8	11.1
Household food security improved	Improved food availability	291	80.6	2	2.8
	Improved food quality/diversity	297	82.3	4	5.6
	Improved purchasing capacity	215	59.6	0	0.0
	No improvement	17	4.7	51	70.8
	Others	139	38.5	6	8.3
Project contribution to enterprise	Improved technical skills	314	87.0	5	6.9
	Improved business skills	282	78.1	2	2.8
	Improved financial management	218	60.4	1	1.4
	Improved market linkages	119	33.0	1	1.4
	Others	177	49.0	42	58.3
Women's participation in project	High participation	194	53.7	0	0.0
	Moderate participation	156	43.2	9	12.5
	Low participation	8	2.2	23	31.9
	No participation	1	0.3	39	54.2
Age group of participants	18-25 years	229	63.4	----	----
	26-35 years	102	28.3	----	----
	36-50 years	26	7.2	----	----
	50+ years	1	0.3	----	----
Recommendations for future	Provide more training	342	94.7	52	72.2
	Improve access to finance	302	83.7	67	93.1

	Strengthen market linkages	200	55.4	63	87.5
	Introduce modern tech	246	68.1	53	73.6
	Focus on women/youth	257	71.2	16	22.2
	Enhance infrastructure	189	52.4	46	63.9
	Others	206	57.1	33	45.8

4. Discussion

From the RMTP endline assessment unequivocally demonstrates that comprehensive agricultural interventions targeting HVF&C can fundamentally transform rural microenterprises, driving profound improvements in HDD and sustainable livelihood metrics.

4.1 Economic transformation as a pathway to nutrition

The transition from staple centric, subsistence agriculture to commercial HVF&C acts as the primary engine for economic uplift (Birtal *et al.*, 2013; Cock, 2020) ^[8, 9]. Beneficiaries significantly outpaced controls in utilizing both owned (98.6%) and leased (85.0%) land for lucrative horticultural crops, moving decisively away from lower-yield cereals. This structural shift yielded substantial economic returns, with 46.5% of beneficiaries reporting high quarterly profits on owned land. According to Pingali (2015) ^[29] and Kuma *et al.* (2019) ^[22], increased agricultural income is arguably the most potent determinant of household food security. The socioeconomic impacts of HVF&C cultivation documented by Parvin *et al.* (2014) ^[28] and Rahman (2017) ^[30] are heavily corroborated by this study's data: as household income grew for 98.3% of beneficiaries, 59.6% reported directly improved purchasing capacity. This liquidity allowed households to transcend mere caloric sufficiency and purchase diverse food groups, directly leading to the 82.3% improvement in food quality and diversity observed among beneficiaries, mirroring the foundational findings of Arimond and Ruel (2004) ^[4] and aligning with the frameworks set forth by the FAO (2011) ^[10].

4.2 The role of market integration and information technology:

A critical bottleneck in rural South Asian agriculture is the fragmented supply chain, which leads to high transaction costs and massive post-harvest losses (Hassan *et al.*, 2010; Torero, 2011) ^[13, 34]. The RMTP successfully dismantled these barriers by establishing direct market linkages and upgrading post-harvest infrastructure. 68.4% of beneficiaries successfully bypassed traditional middlemen to sell directly to consumers and 58.7% integrated with large institutional buyers (Big Arot). Combined with rigorous post-harvest packaging using plastic sacks and polythene (97.0%), beneficiaries effectively curtailed product damage, addressing a vulnerability heavily documented in sub-Saharan and South Asian contexts (Kaminski and Christiaensen, 2014; Light Castle Partners, 2023) ^[19, 23].

Furthermore, the integration of new technologies, such as mobile apps and online platforms, reported by 54.3% of beneficiaries, aligns with Zanello *et al.* (2014) ^[38] and Aker (2011) ^[2], who highlight how ICT drastically lowers transaction costs for rural farmers. This commercial efficiency dramatically enhanced price realization for 62.3% of participants. The literature confirms that such insertion into advanced global and regional retail chains not only secures farmer welfare (Maertens and Swinnen, 2009;

Minten *et al.*, 2009) ^[25, 26] but indirectly elevates local nutritional landscapes by increasing the year round availability of micronutrient rich foods (Humphrey and Schmitz, 2002; Gómez and Ricketts, 2013) ^[16, 11].

4.3 Climate adaptive practices and sustainable intensification:

A standout dimension of the RMTP intervention was its success in embedding sustainable, climate adaptive practices into commercial agriculture. An overwhelming 93.9% of beneficiaries adopted climate-adaptive technologies. The near universal utilization of bio-pesticides (94.5%) and bio-fertilizers (89.2%) indicates a profound behavioral shift toward ecological farming. As noted by Hossain and Pandit (2024) ^[15], Hasan *et al.* (2025) ^[12] and Nale (2025) ^[27], the commercialization and application of bio-pesticides and bio-agents in South Asia are crucial for safe food production and long term soil health. Furthermore, 89.2% of beneficiaries found these organic inputs cost effective compared to synthetic chemicals, mitigating the risks of input driven debt (Kassie *et al.*, 2009) ^[20]. This massive adoption of climate-smart agronomy led to an 82.3% increase in reported yields among beneficiaries. This validates the assertions of Asfaw *et al.* (2016) ^[6] and Lipper *et al.* (2014) ^[24] that localized technological adaptation in vulnerable regions is paramount for maintaining productivity and food security amid climate variability.

4.4 Women's empowerment and intra household dynamics:

Agricultural commercialization can sometimes inadvertently marginalize women; however, the RMTP intervention actively fostered inclusivity (White, 2012; IFAD, 2019) ^[37, 18]. 89.5% of beneficiaries experienced a significant increase in female involvement in financial decision making. Concurrently, 53.7% reported high overall participation of women in project activities. Literature consistently shows a strong positive correlation between women's empowerment in agriculture and household nutritional outcomes (Sraboni *et al.*, 2014) ^[14]. When women exert control over agricultural income and microenterprise decisions, a substantially higher proportion of that income is allocated to dietary diversity and child health (Ruel and Alderman, 2013; Iannotti *et al.*, 2014; FAO, 2011) ^[32, 17, 10]. Therefore, the 82.3% improvement in HDD among the intervention group is inextricably linked to the socio demographic shift empowering women as co-managers of the newly profitable farming enterprises.

4.5 Financial inclusion

Transforming subsistence farming into a competitive business requires robust capital access (Hazell *et al.*, 2014) ^[14]. A highly inclusive financial environment where 95.3% of beneficiaries accessed customized loans, primarily via MFIs/NGOs. In stark contrast, 76.4% of the control group remained financially excluded. By directing these funds toward productive assets specifically, purchasing inputs (52.1%) and securing working capital (50.4%) beneficiaries

could absorb the higher upfront costs of high-value agriculture and modern technology. While high interest rates remain a structural grievance (66.8%), the targeted liquidity provided by the project was instrumental in transitioning these farmers from survivalist models to profitable commercial operations, cementing their capacity to afford a diverse household diet.

5. Conclusion

The comparative endline evaluation validates the efficacy of the RMTP High-Value Fruits and Crops intervention. Beneficiary households transitioned into commercially viable, climate adaptive microenterprises, achieving significantly higher yields, market integration and profitability than their control counterparts. Crucially, these multifaceted economic, technological and structural advancements acted as direct pathways to human development, resulting in a dramatic 82.3% improvement in Household Dietary Diversity and food quality. The integration of women into financial decision making and the massive adoption of eco-friendly bio-inputs further fortified these outcomes. For future scalability, ensuring sustainable access to lower interest agricultural credit and expanding decentralized processing infrastructure will be vital to cementing these transformative gains across Bangladesh.

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