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Economic Appraisal of Protected Horticultural Crop Cultivation in Chhattisgarh, India

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ABSTRACT

This study compares the economic appraisal of Protected Cultivation and Precision Farming (PCPF) compared to open cultivation for various vegetables. The analysis revealed that PCPF demonstrates higher productivity due to improved labor-to-capital ratios, as indicated by the Arithmetic Mean & Geometric Mean (AM-GM) inequality. Indeterminate tomato varieties exhibit superior yields and longer shelf lives under PCPF conditions. Cost analysis showed PCPF reduces operational expenses through efficient drip irrigation and lower plant protection costs, despite higher initial fixed costs. IRR analysis for the Centre of Excellence in Protected Cultivation and Precision Farming (PCPF) revealed a promising financial outlook, with the project generating substantial returns. For instance, the NPV of costs incurred over the years, such as ₹49,51,000 in 2015 and ₹1,99,508.54 in subsequent years, is offset by significant gross returns, including ₹16,33,946.13 and ₹14,34,437.58 in later years. These figures, when discounted at rates of 12%, 44%, and 49%, consistently showed that the present worth of gross returns surpasses the present worth of costs, indicating a robust financial performance. The Benefit-Cost (B: C) ratio analysis indicated significant growth for cabbage, cauliflower, and tomatoes due to higher off-season prices, while knol-khol and brinjal show less change. Overall, PCPF enhances productivity, cost efficiency, and economic returns, underscoring the importance of modern agricultural practices and targeted policies to promote sustainable vegetable cultivation and improve food security and economic resilience. Further analysis has the potential to resolve future challenges such as climate variability, technological adoption constraints, and market access barriers that may hinder long-term sustainability and profitability.

Keywords: *Protected cultivation, precision farming, productivity, cost efficiency, labor, capital, economic returns.*

INTRODUCTION

Chhattisgarh is predominantly an agrarian state, with agriculture constituting a significant portion of its economy and employment. More than 70% of the state's population is engaged in agricultural activities, contributing approximately 25% to its Gross Domestic Product (GDP). The state encompasses 4.78 million hectares of cultivated area, about 35% of its total geographical area, with 23% of this land being irrigated. Predominantly red and yellow soils support the cultivation of rice, wheat, millets, pulses, and oilseeds, with rice covering over 70% of cultivated land and wheat, primarily grown as a rabi crop, occupying about 20%. Despite facing challenges like climate change, water scarcity, and soil degradation, the state government is implementing measures to promote sustainable agricultural practices.

Horticulture in Chhattisgarh is gaining popularity due to the higher value of produce compared to traditional crops, though enhanced irrigation resources and intensive efforts are needed.

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Major fruit crops include mangoes, guavas, limes, litchis, cashew nuts, and cheku (sapota), with minor fruits such as sitafal, bael, ber, and canola also cultivated. In 2020-21, fruit crops covered 2,54,754 hectares, yielding 34,58,745 metric tons. Mangoes are grown statewide, litchis in the northern hilly areas, and cashew nuts in plateau regions. Various vegetables like solanaceous crops, cucurbits, beans, cabbage, and cauliflower were also successfully grown across 4,89,271 hectares, yielding 68,68,126 metric tons in the same period.

LITERATURE REVIEW

[13,14] explored the impact of farm labor supply on hand-harvested fruits and vegetables in California's top 10 counties, finding a 10% decrease led to a maximum 4.2% reduction in production, primarily affecting harvested acreage and yield. [12]studied vegetable cultivation in Kullu valley, revealing tomatoes, cauliflower, and peas exhibit increasing returns to scale (Σbi > 1), highlighting efficiency gains with larger-scale cultivation. [6]identified production and marketing challenges for cole vegetable crops in the Bemetara district, emphasizing improved practices and market efficiency. [3]documented growth in Bilaspur's tomato, cauliflower, and cabbage cultivation, stressing the importance of enhancing agricultural techniques for food security and economic resilience. [7,8,9] showcased the benefits of protected farming and polyhouse development in

enhancing productivity and fostering sustainable economic growth.

Therefore, there is scope for economic analysis of vegetable production under protected cultivation and precision farming, studying variations in productivity with changes in labor and capital under both conditions.

METHODOLOGY

This study investigates the changes in productivity of five key vegetables—tomato, brinjal, cauliflower, knol-khol, and cabbage—cultivated predominantly in the plains of the Mahanadi basin and its tributaries in Chhattisgarh. Productivity estimation was based on two main parameters: labor***(x)***and capital (***y)***, with capital encompassing both fixed capital and machinery used in the production process. Areas for open-field cultivation were purposively selected based on higher production yields, focusing on the districts of Bemetara and Mahasamund. To compare productivity under protected cultivation, trials of the same vegetable categories were conducted at the Centre of Excellence for Protected Cultivation and Precision Farming at Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh (Figure 1&2). The same parameters were employed for consistency. A scatterplot analysis referred from [1,2]for labor and capital in both open and protected conditions led to the formulation of a quadratic equation for optimal fit, enabling precise productivity estimation. The derived quadratic production functions for both conditions are presented in this paper.

In sample collection for primary data, districts situated near the banks of the River Mahanadi and its major tributary (R. Shivnath), known for thehigh productivity of selected vegetables under open conditions, were considered. Following the criteria for selection, Bemetara and Mahasamund districts were chosen. To further reduce selection bias, the selection of blocks and villages was randomized. For Bemetara, the blocks Bemetara and Berla were selected, while for Mahasamund, the blocks Mahasamund and Bagbahara were chosen. The study aimed to gather comprehensive data on agricultural practices and productivity in these regions. Figure 3 & 4 display details for the villages selected.

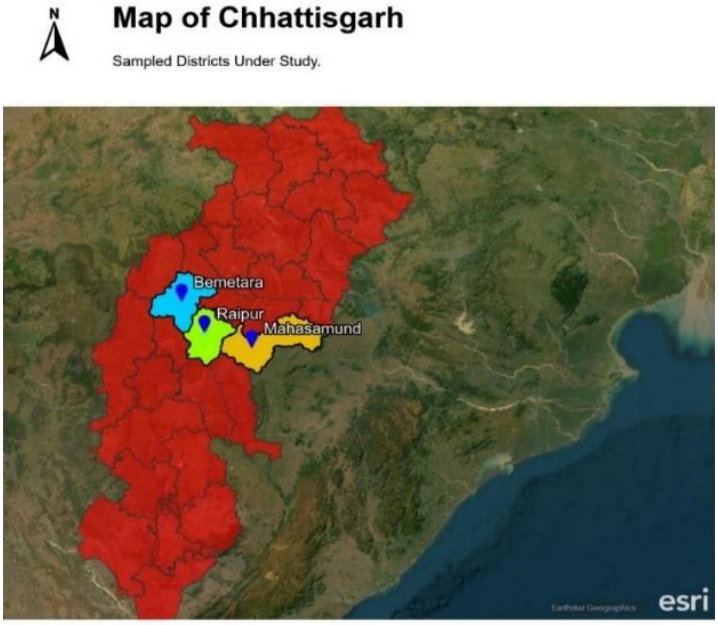


Figure 1. Chhattisgarh and Selected District

Figure 2. Centre of Excellence for Protected Cultivation & Precision Farming at IGKV, Raipur

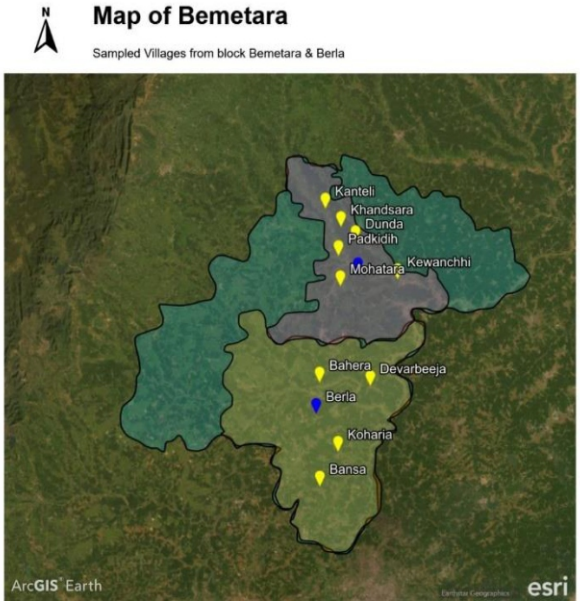


Figure 3. Sampled Villages in Bemetara District

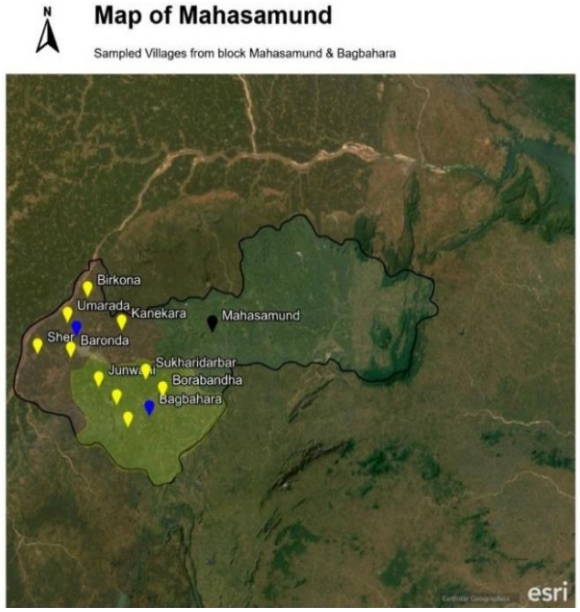


Figure 4. Sampled Villages in Mahasamund District.

The Quadratic production function between Capital and Labor for open cultivation with the coefficient of determination (R^2=0.9977) is:

$$y = 3E-05x^2 - 0.8212x + 33983$$

Similarly, the Quadratic production functionbetween Capital and Labor for protected cultivation with the coefficient of determination (R^2=0.9483) is:

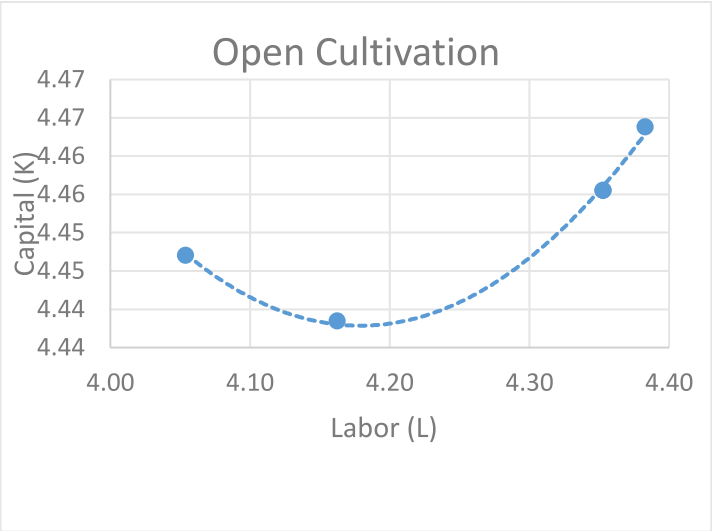
$$y = -0.0008x^2 + 15.373x + 79734$$

For further analysis of productivity due to the introduction of technology (in this case, the Centre of Excellence for Protected Cultivation and Precision Farming), the calculation of the total productivity factor (A) was estimated by deriving equation suggested by [5,10] for production function is illustrated as follows:

$$Since, Y = A * \left(x^{\alpha} * y^{\beta}\right) + \varepsilon$$

$$Therefore, A = \left(\frac{Y}{x^{\alpha} * y^{\beta}}\right) - \varepsilon$$

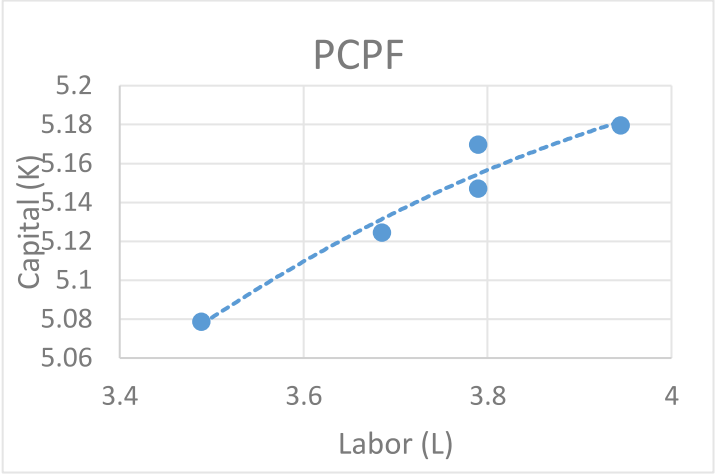
Where A is the total productivity factor and Y represents the gross return for each vegetable. It should be noted that the productivity factor acts as a multiplier to estimate the gross return for each vegetable.



Graph 1. Scatterplot between logarithmic value of Labour and Capital in Open Cultivation.

Table 1. Represents the calibrated value of the Productivity factor

Open Cultivation					PCPF				Percent Change in (A) (%)
Vegetables	Labor (L_o)	Capital(K_o)	Y_o	A_o	Labor (L_p)	Capital(K_p)	Y_p	A_p	
Knol-khol	14532.0	27443.5	237500.0	0.00060	4620.0	48653.7	1827000.0	0.00495	88 %
Brinjal	11320.0	27993.5	182000.0	0.00057	7260.0	48653.7	2349537.1	0.00365	84 %
Cauliflower	22532.0	28543.5	310500.0	0.00048	9240.0	48653.7	629196.4	0.00069	30 %
Tomato	24150.0	29093.5	209000.0	0.00030	13200.0	48653.7	4225714.3	0.00318	91 %
Cabbage	22532.0	28543.5	150000.0	0.00023	9240.0	48653.7	580000.0	0.00067	65 %



Graph 2. Scatterplot between logarithmic value of Labour and Capital under PCPF.

RESULTS

4.1. Relationship between Labor (L) & Capital (K) & estimation of total productivity factor

Equations derived from the scatterplots for open cultivation and Protected Cultivation and Precision Farming (PCPF) indicated that open cultivation exhibits higher labor intensity due to its stronger influence on capital investment in the production process. Graphs 1 and 2 revealed that as the production process advances, the requisite amount of capital, specifically fixed capital, must be increased to yield a greater quantity of vegetables. Conversely, the scatterplot for PCPF suggests that vegetable cultivation under this method is more stable and increasingly labor-intensive over the long term. These findings imply that, in the long-term cultivation of multiple vegetable varieties, fixed costs decrease proportionately to labor. Consequently, the overall cost of production diminishes relative to the concurrent increase in productivity. Furthermore, the scatterplot for open cultivation indicates that increased production necessitates an expansion of land area (includingmaximum fixed capital) under cultivation. This demonstrates that the techniques employed in PCPF enhance productivity without a corresponding increase in the land area under cultivation.This corroborates with the findings of [13, 14] in their study.

From table 1, it can be understood that the total productivity for PCPF was higher than that for open cultivation for every vegetable grown under the two conditions. This difference arises because the ratio of labor to capital was different for both conditions, a property described by the AM-GM inequality. [4] suggested that for any non-negative real numbers a and b: $\frac{a+b}{2} \geq \sqrt{ab}$, Equality holds if and only if a = b. In the case of open cultivation, the ratio between labor and capital leaned more towards equality. Therefore, the value of A, which inversely represents the relationship for the Arithmetic Mean-Geometric Mean inequality of labor and capital, was influenced accordingly. Another parameter influencing total productivity is the overall output, which was found to be higher for PCPF $(i.e. Y_p > Y_o)$. From Table 1, it can be observed that the change in the total productivity factor between open cultivation and PCPF was highest for tomatoes, followed by knol-knol, and then by brinjal. The least change in the total productivity factor could be seen in cauliflower. These results can be interpreted for two reasons. Firstly, the selection of indeterminate varieties of tomatoes, specifically BS-1006 (Yuvraj) and Syngenta-Saaho, for production in PCPF showed higher productivity compared to open cultivation.

These indeterminate varieties adapted better to the conditions of PCPF, as evidenced by their longer shelf life and increased fruit production due to branching, whereas these varieties are fragile in open conditions. Meanwhile, the quality of cabbage and cauliflower increased with size, resulting in increased productivity per head, though the count remained the same due to their yield characteristics.

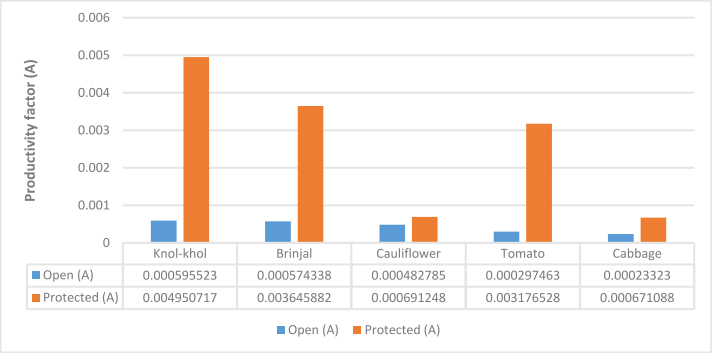


Figure 5. Comparison between open cultivation and PCPF for productivity factor (A)

From Figure 5, it can be observed that the total productivity factor for all the sampled vegetables cultivated in protected cultivation using polyethylene film (PCPF) was higher than for those cultivated under open conditions. It could be observed that maximum productivity was obtained for knol-khol (var. Ajeet Bolero). This result may be attributed to the two criteria selected. The first criterion is varietal selection, and the second is the increase in the weight per headcount of knol-khol. Meanwhile, the second-highest productivity was observed for brinjal, followed by tomato, which could be due to their varietal selection (indeterminate varieties such as BS-1006 (Yuvraj) and Syngenta-saho) and their longer shelf-life under PCPF conditions. The duration from the first harvest to the last for brinjal and tomato was found to be 250 days and 120 days, respectively. This was possible because the PCPF provided supportive conditions for the vegetables, enabling them to thrive in harsh weather and reducing pest infestation, thereby increasing the duration of crop yield.

4.2. Cost of cultivation for both conditions

From Tables 2 and 3, it can be inferred that the cost of cultivation differs significantly between the two conditions. The three major areas of crop production affected were human labor, operational costs, and fixed costs. Firstly, more labor was required for open cultivation of all the vegetables grown under both open conditions and PCPF. This is because growing vegetables in open conditions require more rigorous management practices. In contrast, management in protected cultivation is more convenient as most processes are automated. Secondly, the overall operational cost was lower in PCPF compared to open cultivation. The most significant reduction in operational cost was in the amount of seed required, which was much lower than in open cultivation. This can be attributed to the higher viability of seedlings generated in PCPF. Additionally, reductions in operational costs were seen in irrigation and plant protection. Drip irrigation, adopted in PCPF, was more efficient than traditional methods used in open cultivation. Similarly, plant protection costs were higher for open cultivation due to greater infestation by entomological and pathological agents. Although the initial fixed cost was higher for PCPF due to its structural components and the heavy investment required for establishment, it was found to be more stable in the long run, as displayed by the Scatterplot diagram in Graph 2.

Table 2. Cost of cultivation for vegetables grown in open condition

Particulars		CAULIFLOWER	Cabbage	Knol-khol	Tomato	Brinjal
Labour cost	Human labour	₹ 22,400.00	₹ 22,400.00	₹ 14,400.00	₹ 24,000.00	₹ 11,200.00
	Family	₹ 5,600.00	₹ 5,600.00	₹ 3,600.00	₹ 6,000.00	₹ 2,800.00
	Hired	₹ 16,800.00	₹ 16,800.00	₹ 10,800.00	₹ 18,000.00	₹ 8,400.00
	Bullock labour	₹ 132.00	₹ 132.00	₹ 132.00	₹ 150.00	₹ 120.00
	Machine power	₹ 2,200.00	₹ 2,200.00	₹ 1,100.00	₹ 2,750.00	₹ 1,650.00
	Total	₹ 22,400.00	₹ 22,400.00	₹ 14,400.00	₹ 24,000.00	₹ 11,200.00
Operational Cost	Seed	₹ 10,150.00	₹ 8,000.00	₹ 10,560.00	₹ 11,295.70	₹ 1,300.00
	Manure & Fertilizers	₹ 13,859.74	₹ 18,582.14	₹ 17,754.00	₹ 20,245.50	₹ 13,424.97
	Plant protection	₹ 10,500.00	₹ 8,446.50	₹ 7,101.50	₹ 6,135.00	₹ 6,102.26
	Irrigation	₹ 2,400.00	₹ 2,712.00	₹ 4,260.00	₹ 3,214.28	₹ 6,090.92
	Interest on working capital	₹ 2,465.67	₹ 2,498.91	₹ 2,212.30	₹ 2,711.62	₹ 1,595.53
	Miscellaneous	₹ 5,930.97	₹ 6,014.06	₹ 5,407.55	₹ 6,489.05	₹ 3,971.37
	Total	₹ 45,306.38	₹ 46,253.60	₹ 47,295.35	₹ 50,091.15	₹ 32,485.04
Fixed Cost	Land revenue	₹ 353.66	₹ 353.66	₹ 353.66	₹ 353.66	₹ 353.66
	Depreciation	₹ 20.00	₹ 20.00	₹ 20.00	₹ 20.00	₹ 20.00
	Interest on fixed capital	₹ 23,575.00	₹ 23,575.00	₹ 23,575.00	₹ 23,575.00	₹ 23,575.00
	Rental value of owned land	₹ 2,394.87	₹ 2,394.87	₹ 2,394.87	₹ 2,394.87	₹ 2,394.87
	Total fixed cost	₹ 26,343.53	₹ 26,343.53	₹ 26,343.53	₹ 26,343.53	₹ 26,343.53
Total cost of cultivation		₹ 71,649.91	₹ 72,597.13	₹ 73,638.88	₹ 76,434.68	₹ 58,828.57
						(in Rs. Per Ha)

Table 3. Cost of cultivation for vegetables grown in PCPF

S.No.	Name of Structures	Quantity	Per Unit Area (in Sq.mtrs)	per unit cost	Life term	Total Cost
1	**Naturally Ventilated Poly-houses**	4	696	₹ 350.00	15	₹ 2,43,600.00
2	**Walk-in-Tunnel**	8	696	₹ 150.00	15	₹ 1,04,400.00
3	**White net house**	2	6000	₹ 250.00	15	₹ 15,00,000.00
4	**Seed Liner**	1	-	₹ 35,000.00	15	₹ 35,000.00
5	**Germination Chamber**	1	7 x 6	₹ 2,50,000.00	15	₹ 2,50,000.00
6	**Primary hardening Chamber**	1	96 x 9.6	₹ 15,00,000.00	15	₹ 15,00,000.00
7	**Secondary Hardening chamber**	1	36 x 9.6	₹ 8,00,000.00	15	₹ 8,00,000.00
8	**Solar cold storage**	1	-	₹ 4,50,000.00	15	₹ 4,50,000.00
9	**Water harvesting tank with poly lining**	1	-	₹ 50,000.00	15	₹ 50,000.00
10	**Control Unit**	1	-	₹ 18,000.00	15	₹ 18,000.00
Total =						**₹ 49,51,000.00**

Total Area (in Sq.mtr)	*21,353*
Cost per hectare @1000sq.mtr	*₹ 24,32,684.75*
Junk Value	*₹ 2,43,268.5*
Discounted Value	*₹1,45,961.08*
Value of Capital for PCPF on each crop @3 crop per year	***₹ 48,653.69***
Interest on Fixed Value	***₹ 12,163.42***
Deprecation Value per crop@10%	***₹ 4,865.37***
Land Value	***₹2,394.87***

S.No.	CROP/Vegetables	TVC (A)	TFC (B)	*Total (A+B)*
1	Cabbage	₹ 41,392.11	₹ 68,077.35	*₹ 1,09,469.46*
2	Cauliflower	₹ 48,853.98	₹ 68,077.35	*₹ 1,16,931.33*
3	Knol-khol	₹ 20,906.23	₹ 68,077.35	*₹ 88,983.58*
4	Tomato	₹ 52,258.58	₹ 68,077.35	*₹ 1,20,335.93*
5	Brinjal	₹ 34,236.77	₹ 68,077.35	*₹ 1,02,314.12*
(in Rs. Per Ha)				

It is worth mentioning that the government is aware of the substantial investment needed to establish protected structures for cultivation such as PCPF. As a result, they have implemented a policy of providing a 50% subsidy on the overall cost of structural components in PCPF. Additionally, to ensure the sustainability of these structures, insurance was provided by banking institutions annually.

4.3. Cost and Return

From Tables 4 and 5, it can be observed that the B: C ratio for cabbage, cauliflower, and tomatoes saw significant growth of approximately 3.5x, 5.56x, and 9.07x, respectively. These increases were likely due to the higher price these crops fetched during the off-season, driven by a rightward shift in demand[5]. In contrast, relatively less change was observed for Knol-khol and Brinjal for two reasons. Firstly, the production estimate for knol-khol was based on a small sample size of one line (145 m^2), compared to larger sample sizes for other crops with multiple replications. Secondly, the demand for brinjal was comparatively lower due to their larger size compared to market offerings. This may be related to the psychological behavior of consumers, who prefer to buy more per unit count of smaller brinjals to reduce the chances of rotting through pathogens.

Table 4. Cost and Return Analysis for vegetables in Open condition and PCPF.

Vegetables	Open Cultivation			PCPF		
	Total Cost (Includes Insurance)	Gross Return	B:C Ratio (x_0)	Total Cost (Includes Insurance)	Gross Return	B:C Ratio
Cabbage	73109.1	237500.0	3.2	161469.5	1827000.0	11.3
Cauliflower	72161.9	182000.0	2.5	168931.3	2349537.1	13.9
Knol-khol	74150.9	310500.0	4.2	140983.3	629196.4	4.5
Tomato	76946.7	209000.0	2.7	172335.9	4225714.3	24.5
Brinjal	59340.6	150000.0	2.5	154314.1	580000.0	3.8

4.4. Internal Rate of Return (IRR)& Net Present Value (NPV) Analysis

The results of the IRR and NPV analysis for the Center of Excellence in Protected Cultivation and Precision Farming (PCPF) manifested in Table 6 demonstrate the financial viability and profitability of adopting advanced agricultural technologies. The IRR, though not explicitly stated due to the mid-term evaluation of the project, was implied to be favorable, indicating a positive return on investment. The NPV calculations revealed that the present worth of gross returns exceeds the present worth of costs at various discount rates (12%, 44%, and 49%), which confirmed the economic feasibility of the project. The study's findings were found to be consistent with previous research by [8], who highlighted the opportunities and challenges of protected cultivation, noting its potential to enhance productivity and profitability.

Overall, the PCPF technology not only improves agricultural productivity but also offers a financially sustainable model for farmers, as evidenced by the favorable IRR and NPV results. The positive financial outcomes of the PCPF project underscored its potential to transform horticultural practices in Chhattisgarh, offering a sustainable and economically viable solution for increasing agricultural productivity[11,15,16].

Table 5. Cost of cultivation for vegetables grown in open conditions (in Rs. Per Ha).

Particulars		Cauliflower (₹)	Cabbage (₹)	Knol-khol (₹)	Tomato (₹)	Brinjal (₹)
Labor cost	Human labour	22,400.00	22,400.00	14,400.00	24,000.00	11,200.00
	Family	5,600.00	5,600.00	3,600.00	6,000.00	2,800.00
	Hired	16,800.00	16,800.00	10,800.00	18,000.00	8,400.00
	Bullock labour	132.00	132.00	132.00	150.00	120.00
	Machine power	2,200.00	2,200.00	1,100.00	2,750.00	1,650.00
	Total	22,400.00	22,400.00	14,400.00	24,000.00	11,200.00
	% of total cost	24%	24%	16%	24%	16%
Operational Cost	Seed	10,150.00	8,000.00	10,560.00	11,295.70	1,300.00
	Manure & Fertilizers	13,859.74	18,582.14	17,754.00	20,245.50	13,424.97
	Plant protection	10,500.00	8,446.50	7,101.50	6,135.00	6,102.26
	Irrigation	2,400.00	2,712.00	4,260.00	3,214.28	6,090.92
	Interest on working capital	2,465.67	2,498.91	2,212.30	2,711.62	1,595.53
	Miscellaneous	5,930.97	6,014.06	5,407.55	6,489.05	3,971.37
	Total	45,306.38	46,253.60	47,295.35	50,091.15	32,485.04
	% of total cost	48%	49%	54%	50%	46%
Fixed Cost	Land revenue	353.66	353.66	353.66	353.66	353.66
	Depreciation	20.00	20.00	20.00	20.00	20.00
	Interest on fixed capital	23,575.00	23,575.00	23,575.00	23,575.00	23,575.00
	Rental value of owned land	2,394.87	2,394.87	2,394.87	2,394.87	2,394.87
	Total fixed cost	26,343.53	26,343.53	26,343.53	26,343.53	26,343.53
	% of total cost	28%	28%	30%	26%	38%
Total cost of cultivation		94,049.910	94,997.130	88,038.880	1,00,434.680	70,028.570

Table 6. IRR & NPV estimated for Center of Excellence at PCPF.

Year	Cost (in Rs./₹)	NPV of Cost incurred	Gross return (in Rs./₹)	Net Return (in Rs./₹)	Discount Factor (@12%)	Present worth of costs (in Rs./₹)	Present worth of gross return (in Rs./₹)	Discount factor (44%)	NPV (Discount rate @40 %)	Discount factor (50%)	NPV (Discount rate @50 %)
2015	49,51,000.00		₹ 0.00	-49,51,000.00	1	49,51,000.00	-	1	-49,51,000.00	1	-49,51,000.00
2016	1,99,508.54	1,78,132.63	16,33,946.13	14,34,437.58	0.893	1,78,132.63	14,58,880.47	0.714	10,24,598.27	0.667	9,56,291.72
2017	5,58,623.92	4,45,331.57	23,06,747.47	17,48,123.55	0.797	4,45,331.57	18,38,924.96	0.510	8,91,899.77	0.444	7,76,943.80
2018	6,38,427.34	4,54,419.97	34,60,121.21	28,21,693.87	0.712	₹ 4,54,419.97	24,62,845.93	0.364	10,28,314.09	0.296	8,36,057.44
2019	7,18,230.75	4,56,448.63	41,32,922.55	34,14,691.80	0.636	₹ 4,56,448.63	26,26,547.00	0.260	8,88,872.29	0.198	6,74,507.02
2020	7,58,132.46	4,30,184.72	49,01,838.38	41,43,705.92	0.567	₹ 4,30,184.72	27,81,434.74	0.186	7,70,457.61	0.132	5,45,673.21
2021	7,90,053.83	4,00,265.86	54,78,525.25	46,88,471.42	0.507	₹ 4,00,265.86	27,75,591.39	0.133	6,22,677.34	0.088	4,11,607.92
2022	7,95,123.50	3,59,673.49	61,51,326.59	53,56,203.09	0.452	₹ 3,59,673.49	27,82,547.76	0.095	5,08,113.56	0.059	3,13,486.05
2023	7,98,034.17	3,22,312.62	96,11,447.80	88,13,413.63	0.404	₹ 3,22,312.62	38,81,902.56	0.068	5,97,200.09	0.039	3,43,885.67
						IRR =	49.37199968	Σ=	13,81,133.03		-92,547.16

CONCLUSION

The study highlights the significant advantages of Protected Cultivation and Precision Farming (PCPF) over open cultivation. PCPF demonstrates higher productivity due to better labor-to-capital ratios, supported by the AM-GM inequality. Indeterminate tomato varieties, such as BS-1006 (Yuvraj) and Syngenta-Saaho, show superior productivity under PCPF conditions, with increased fruit production and longer shelf life. Cost analysis reveals that PCPF reduces operational costs through efficient drip irrigation and lower plant protection expenses, despite higher initial fixed costs. Government subsidies and annual insurance further enhance the economic viability of PCPF. The Benefit-Cost (B:C) ratio analysis shows substantial growth for cabbage, cauliflower, and tomatoes due to higher off-season prices, except Knol-Khol and Brinjal exhibit less change due to sample size and consumer preferences. These findings were found to be similar to the study of [12] for vegetables in higher altitudes.

Overall, PCPF offers significant benefits in terms of productivity, cost efficiency, and economic returns compared to open cultivation. These findings underscore the importance of adopting modern agricultural practices and implementing targeted policies to promote sustainable vegetable cultivation, enhancing food security and economic resilience in the agricultural sector.

FUTURE SCOPE OF THE STUDY

The future scope of this study includes expanding protected

cultivation models to diverse agro-climatic zones and integrating automation technologies like AI-driven irrigation and climate control. Further research can analyze financial sustainability, market linkages, and climate resilience to enhance profitability. Investigating socio-economic barriers, farmer perceptions, and policy interventions will aid adoption. Comparative studies between protected and open cultivation can refine best practices while integrating IoT and big data analytics can improve precision farming efficiency. Addressing these areas will promote sustainable agriculture in Chhattisgarh, ensuring economic benefits and long-term viability for protected horticultural crop cultivation.

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