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Growth and Trend Analysis of Area, Production, and Productivity of Fennel (*Foeniculum vulgare* Mill.) in India

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Abstract

Fennel (*Foeniculum vulgare* Mill.) has demonstrated remarkable commercial potential across diverse industries. It has been widely recognized for its rich phytochemical composition, including essential oils, flavonoids, phenolic compounds, and dietary fiber. This study aimed to estimate the Compound Annual Growth Rate (CAGR) and analyze linear trends in area, production, and productivity of fennel (*Foeniculum vulgare* Mill.) cultivation in India over a 30-year period. A quantitative, descriptive research study based on secondary time-series data employing linear trend analysis and CAGR computation. The study covered fennel cultivation across India, with particular reference to leading producer states — Gujarat, Rajasthan, and

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Madhya Pradesh — spanning the period from 1994–95 to 2023–24. Secondary time-series data (N = 30) were sourced from Indiastat, the Department of Agriculture (Rajasthan), and the Board of Revenue (Rajasthan). Three parameters — area (thousand hectares), production (thousand MT), and productivity (MT/hectare) — were analyzed using semi-log regression (linear trend analysis Y=a+bX) and CAGR, computed as $CAGR = \left(\frac{V_f}{V_i}\right)^{\frac{1}{n}} - 1$

The average area, production, and productivity were 59.62 thousand hectares, 90.79 thousand MT, and 1.41 MT/hectare, respectively. Area grew at a CAGR of 6.89% ($R^2 = 0.78$), production at 8.73% ($R^2 = 0.84$), and productivity at 1.69% ($R^2 = 0.68$). Production exhibited the highest variability (CV = 0.78), while productivity remained relatively stable (CV = 0.17). A notable production surge was recorded in 2023–24, reaching 376.05 thousand MT over an area of 216.02 thousand hectares. Fennel cultivation in India demonstrated a consistent and statistically significant positive growth trajectory across all three dimensions over the 30-year study period. The production growth rate surpassing both area and productivity growth rates individually indicates a combined effect of increased land allocation and improved farming efficiency. The unprecedented 2023–24 surge warrants further investigation into its contributing factors and long-term sustainability.

Keywords: Fennel; area; production; productivity; growth; trend analysis; CAGR etc.

1. Introduction

Fennel (*Foeniculum vulgare* Mill.) is a multiuse herb of ancient origin that holds great economic and cultural significance worldwide. Its adaptability to diverse environmental conditions has enabled its cultivation across the Mediterranean basin, India, and various regions of Asia, Europe, and America. Historically, fennel has been referenced as **"**madhurika**"** in ancient Sanskrit texts, symbolizing victory in ancient Greece and success in Rome, and even serving as one of nine sacred herbs in Anglo-Saxon tradition (Mehta, et al*.,* 2021). Fennel is a highly aromatic and flavorful seed spice crop valued for its culinary and medicinal applications. Therefore, it is extensively used in soups, salads, baked goods, liqueurs, and the pharmaceutical industry (Diaaz-Maroto et al*.,* 2005, Dolai & Mondal, 2023).

India stands as one of the world's largest fennel producers, with Gujarat, Rajasthan, and Madhya Pradesh being the leading cultivating states. In Gujarat, fennel ranks as the third most cultivated spice, contributing significantly to the state's overall spice production (Patel et al*.,* 2025). FAO and India's Spices Board (MoCI) issued a "Good Agricultural Practices (GAP)" package for fennel (Gujarat & Rajasthan) in March 2023. The inclusion of fennel as the ODOP product for Sirohi district, Rajasthan, under the PMFME Scheme represents a landmark opportunity for the holistic development of the fennel value chain in the region. Rajasthan and Gujarat together account for more than 90% of the total fennel production in the country, making them the most dominant fennel-producing states (Mehta et al. 2021).

List 1. Major fennel producing states in india from 2019-20 to 2023-24

Major States	2019-20		2020-21		2021-22		2022-23		2023-24	
	Area (ha)	Prod. (Tons)	Area (ha)	Prod. (Tons)	Area (ha)	Prod (Tons)	Area (ha)	Prod (Tons)	Area (ha)	Prod (Tons)
Gujarat	52.8	109.03	48.44	98.58	41.96	87.17	56.81	117.84	140.72	294.6
Rajasthan	26.25	25.62	30.81	33.56	19.37	22.83	28.1	29.31	71.95	76.75
Madhya Pradesh	1.56	2.77	1.58	2.85	1.62	2.94	1.59	2.91	1.6	2.87
West Bengal	1.05	1.08	1.05	1.07	1.01	1.05	0.86	0.96	0.77	0.86
Uttar Pradesh	0.74	0.08	0.72	0.78	0.83	0.79	0.87	0.85	0.94	0.95
Total (incl. others)	83	140	82.77	137.39	64.92	114.97	88.3	151.94	216.02	376.05

Source: INDIASTAT (2025)

1.1 Problem Statement

Despite fennel's growing economic importance in India, there exists a significant gap in knowledge regarding its long-term growth patterns and production trends at the national level (Magon et al., 2025). While individual state-level studies have been conducted, a comprehensive 30-year analysis covering area, production, and productivity simultaneously — and incorporating the most recent data up to 2023-24 — has been largely absent. Furthermore, the notable and unprecedented surge in production observed in 2023-24 raises critical questions about the sustainability and contributing factors of this growth, which remain unexplored. Without a systematic understanding of these trends, policymakers, farmers, and agribusiness stakeholders lack the evidence base needed to make informed decisions regarding fennel cultivation and value chain development.

1.2 Proposed Solution

This study proposes to address the identified knowledge gap by conducting a rigorous quantitative analysis of the area, production, and productivity of fennel in India over a 30-year period (1994-95 to 2023-24). Using secondary time-series data sourced from authenticated repositories, the study employs linear trend analysis and Compound Annual Growth Rate (CAGR) computation to capture the temporal dynamics of fennel cultivation. The study also aims to assess the economic viability of fennel production and identify potential areas for improvement, including the scope for value addition to enhance economic benefits for farmers.

2. Literature Review

Kumawat and Meena (2005) observed that both Rajasthan and India witnessed a good increase in fennel production during the period 1986-1987 to 2000-2001. They found that increased area, rather than productivity, mainly contributed to the growth in production. By the turn of the millennium, Rajasthan had become the leader, accounting for almost 24% share in area as well as production of the crop at the national level.

Bairwa et al. (2022) found that the compound annual growth rate of fennel production in Rajasthan was very high (around 11.15 percent) during the overall period (1991–92 to 2019–20), which indicated that the fennel crop is expanding rapidly in Rajasthan.

Singh (2017) stated in his study that the performance of improved fennel varieties through found superior to the farmers' practice. Among the fennel varieties tested, RF-125 recorded the highest yield of 23.80 q/ha, followed by RF-145 (23.60 q/ha), RF-101 (22.93 q/ha), and RF-205 (22.30 q/ha), as compared to the farmers' practice (20.10 q/ha), indicating a 10.95 to 18.41% yield increase. It was observed from the results that there was a technology gap of 1.20 to 2.70 q/ha and extension gap of 2.20 to 3.70 q/ha, which indicates the need to adopt fennel cultivation technologies among farmers on a larger scale.

A study by Dolai and Mondal (2026) investigated the growth trajectory and structural evolution of India's agricultural GDP from 1960-61 to 2019-20. Utilizing a log-linear growth model, they calculated the Compound Annual Growth Rate (CAGR) and analyzed growth patterns across distinct structural periods identified via the Modified Bai-Perron method. The CAGR was derived from the estimated instantaneous growth rate (b) in the semi-logarithmic equation $\ln(Yt) = a + bt$, using the formula $CAGR = [\exp(b) - 1] \times 100$.

The Compound Annual Growth Rate (CAGR) for a variable Yt relative to the preceding year (t-1) is calculated using a standard formula derived from the principles of compound growth. This method assumes a consistent trend growth rate, which can be estimated through a regression analysis. Specifically, by taking the natural logarithm of the variable and regressing it against time (t), the coefficient of t in this regression provides an estimate for the growth rate. This estimate is then converted to the CAGR by exponentiating the coefficient and subtracting one, with the result expressed as a percentage.

2.1 Objective of the Study

a) To analyze the trends in area, production, and productivity of fennel (*Foeniculum vulgare* Mill.) in India over a period of 30 years.
b) To estimate the Compound Annual Growth Rate (CAGR) of area, production, and productivity of fennel cultivation in India during the study period.

3. Methodology

A linear trend analysis was used to determine and interpret long-term directional changes in area, production, and productivity of fennel during the study period. This allowed to obtain an approximate sense of the nature of the trend, and its direction in time.

$$Y = a + bX$$

Where:

Y = Production
X = Time (Year)
a = Intercept
b = Trend coefficient

Alongside trend analyses, other descriptive statistics, including means, standard deviations and coefficients of variation were also calculated. On top of that, Compound Annual Growth Rate (CAGR) was measured for all three variables to determine the average annual growth rate throughout the period of study. The compound annual growth rate (CAGR) was then calculated as follows:

$$CAGR = \left(\frac{V_f}{V_i}\right)^{\frac{1}{n}} - 1$$

Where,

$V_f = final\ value$
$V_i = initial\ value$
$n = final\ value$

The application of both trend analysis and computation of growth rates, offered valuable insights on the status of fennel cultivation in India for the last 30 years.

4. Result and Discussion

The present study examines the growth performance and trend analysis of fennel (Foeniculum vulgare Mill.) in India over a period of 30 years, encompassing the dimensions of area, production, and productivity. The secondary data collected from various authentic sources were subjected to rigorous statistical and econometric tools, including Compound Annual Growth Rate (CAGR) and trend analysis, to capture the temporal dynamics of fennel cultivation in India. Agricultural output growth is typically modeled using growth analysis, which quantifies observed temporal patterns. A prevalent methodology in this field is the semi-log-linear regression equation, employed to elucidate the dynamics of this growth (Dolai, 2025).

4.1 Growth and Trends in Area of Fennel in India (1994-95 to 2023-24)

A semi-log regression analysis was conducted to model the growth trend of fennel cultivation area in India from 1995 to 2024. The analysis revealed a significant positive relationship between time and cultivated area, as indicated by a Multiple R of 0.88. The R-squared value of 0.78 suggests that approximately 78% of the variation in fennel cultivation area is explained by the time trend, with the Adjusted R-squared value of 0.77 reinforcing this finding.

The regression model produced a statistically significant intercept (coefficient = 2.85, t = 24.04, $p < 0.001$). Importantly, the coefficient for time (0.07, t = 9.98, $p < 0.001$) demonstrated a statistically significant positive growth trajectory in the area dedicated to fennel cultivation throughout the study period. The antilog of the time coefficient translated to a Compound Annual Growth Rate (CAGR) of 6.89% per annum.

Table 1. Area, Production and Productivity of Fennel in India (1994-95 to 2023-24)

S.No.	Year	Area (In '000 Hectare)	Production (In '000 MT)	Productivity (In MT/Hectare)
1	1994-1995	16.7	17.4	1
2	1995-1996	12.8	15.7	1.2
3	1996-1997	25.1	28.4	1.1
4	1997-1998	26.8	36.6	1.4
5	1998-1999	17.1	23.5	1.4
6	1999-2000	18.2	19.3	1.1
7	2000-2001	25.8	27.3	1.1
8	2001-2002	39.9	38.5	1
9	2002-2003	22.9	27.6	1.2
10	2003-2004	43	51.8	1.2
11	2004-2005	39.8	51	1.3
12	2005-2006	40.9	61.3	1.5
13	2006-2007	61.1	92.3	1.5
14	2007-2008	49	62	1.3
15	2008-2009	47.16	64.29	1.4
16	2009-2010	50.67	56.55	1.1
17	2010-2011	61.8	105.4	1.7
18	2011-2012	99.6	143	1.4
19	2012-2013	99.6	143	1.4
20	2013-2014	94.1	135.9	1.4
21	2014-2015	38.7	59.8	1.5
22	2015-2016	76	129	1.7
23	2016-2017	91	153	1.7
24	2017-2018	66	104	1.6
25	2018-2019	90	157	1.7
26	2019-2020	83	140	1.69
27	2020-2021	82.77	137.39	1.66
28	2021-2022	64.92	114.97	1.77
29	2022-2023	88.3	151.94	1.72
30	2023-2024	216.02	376.05	1.74

Source: (Indiastat, 2025)

Table 2. Regression statistics and CAGR of area under fennel crop in India (1995 to 2024)

Multiple R			0.88	
R Square			0.78	
Adjusted R Square			0.77	
Standard Error			0.31	
Observations			30	
	Coefficients	**Standard Error**	**t Stat**	**P-value**
Intercept	2.85	0.12	24.04	0.00
X(Time)	0.07	0.01	9.98	0.00
Antilog(X)	1.06			
CAGR (Area)	6.89			

Source: Researcher's computation from secondary data (Indiastat, 2025)

Trend analysis indicated that the area under fennel showed a positive trend over the study period. The fitted regression equation ($y = 2.85 + 0.07(x)$) indicated that the area under fennel grew steadily over the study period. The coefficient of determination ($R2 = 0.78$) indicated that 78 per cent of the variation in area is due to the time trend.

The expansion in fennel cultivation is attributable to a confluence of economic, institutional, and policy factors. Increased domestic and international demand, particularly from the spice processing and pharmaceutical sectors,

alongside growth in EU and Gulf markets, has rendered fennel cultivation more economically viable for farmers, encouraging the cultivation of larger areas. These findings are broadly consistent with rapid areal expansion of fennel seed crop in India.

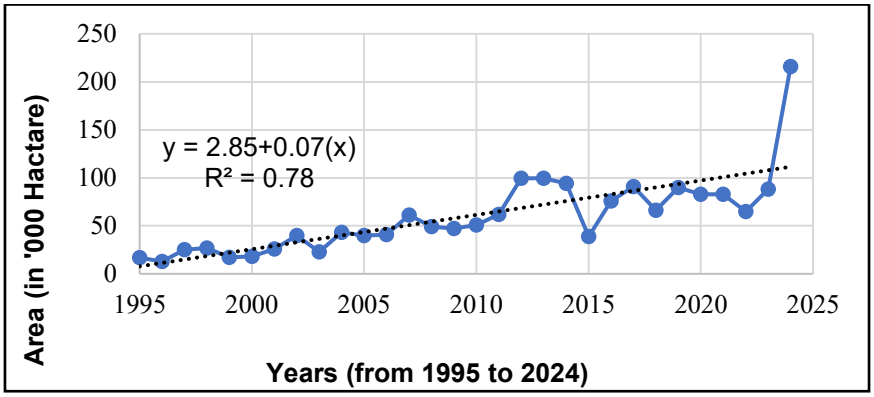


Fig. 1. Trend analysis of area under fennel crop in India from 1995 to 2024
Source: Researcher's computation from secondary data (Indiastat, 2025)

4.2 Growth and Trends in Production of Fennel in India (1994-95 to 2023-24)

A regression analysis of Indian fennel production from 1995 to 2024 revealed a significant positive trend. Table 3 shows the high Multiple R (0.91) and R^2 (0.84) indicate that time explains approximately 84% of the production variation. The statistically significant positive regression coefficient for time (0.08) and a Compound Annual Growth Rate (CAGR) of 8.73% underscore a consistent and substantial increase in production over the period. The model's reliability is supported by significant t- and p-values.

Table 3. Regression statistics and CAGR of production under fennel crop in India (1995 to 2024)

Multiple R			0.91	
R Square			0.84	
Adjusted R Square			0.83	
Standard Error			0.32	
Observations			30	
	Coefficients	**Standard Error**	**t Stat**	**P-value**
Intercept	2.92	0.12	23.91	0.00
X(Time)	0.08	0.01	12.18	0.00
Antilog(X)	1.08			
CAGR(Production)	8.73			

Source: Researcher's computation from secondary data (Indiastat, 2025)

The production trend indicates a positive growth in fennel production in India. The fitted linear trend equation $y=6.6216x-13215$ reveals that fennel production increased annually by about 6.62 thousand metric tonnes during the study period. The coefficient of determination ($R2=0.6409$) indicates that nearly 64.09 per cent of the variation in fennel production is explained by the time trend, suggesting a moderately strong upward trend. Importantly, the CAGR of production (8.73%) consistently outpaced the CAGR of area (6.89%), indicating that production gains have been driven not merely by bringing more land under the crop but also by efficiency improvements within the existing cultivation base.

The remarkable fennel production of 376.05 thousand MT in 2023–24, a 147% increase from the previous year, merits detailed analysis. This surge is likely due to favorable agroclimatic conditions in the 2023–24 rabi season, expanded cultivation area, enhanced seed availability from government initiatives, and potential improvements in state-level data reporting. Future data will be crucial to determine if this represents a sustainable structural change or a temporary peak in production.

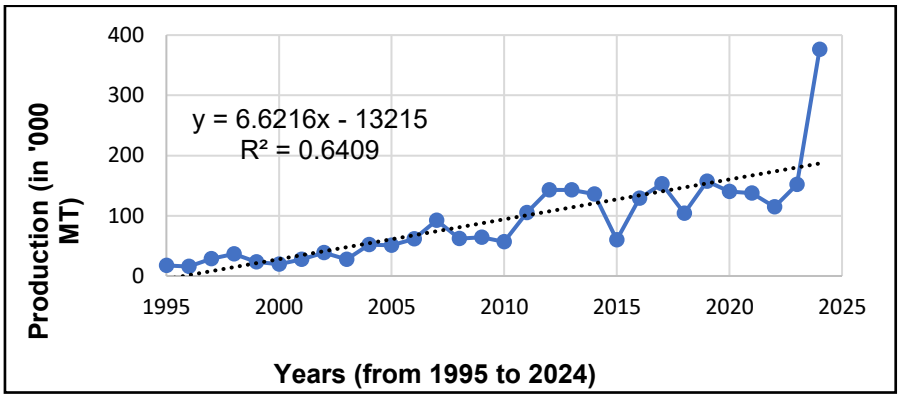


Fig. 2. Trend analysis of production under fennel crop in India from 1995 to 2024
Source: Researcher's computation from secondary data (Indiastat, 2025)

4.3 Growth and Trends in Productivity of Fennel in India (1994-95 to 2023-24)

Regressions of Indian fennel productivity from 1995 to 2024 show significant positive trend (Multiple R = 0.82). The model explained 68% of the variation in productivity (R2 = 0.68), and has a statistically significant positive regression coefficient for time (0.02), indicating a steady increase in productivity. The annual rate of compound growth is estimated at 1.69%, indicating moderate productivity growth. Significant t- and p-values indicate reliability of the model in forecasting trends.

Table 4. Regression statistics and CAGR of productivity under fennel crop in India (1995 to 2024)

Multiple R			0.82	
R Square			0.68	
Adjusted R Square			0.66	
Standard Error			0.10	
Observations			30	
	Coefficients	**Standard Error**	**t Stat**	**P-value**
Intercept	0.07	0.04	1.87	0.07
X(Time)	0.02	0.00	7.72	0.00
Antilog(X)	1.01			
CAGR(Productivity)	1.69			

Source: Researcher's computation from secondary data (Indiastat, 2025)

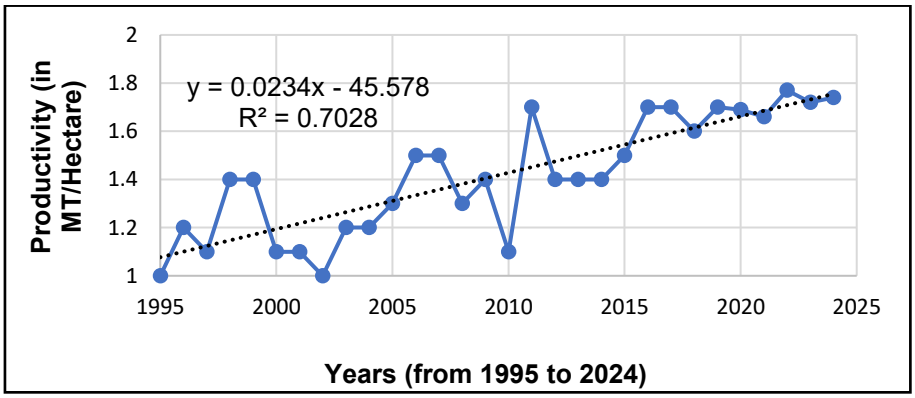


Fig. 3. Trend analysis of productivity under fennel crop in India from 1995 to 2024
Source: Researcher's computation from secondary data (Indiastat, 2025)

The productivity trend was positively skewed, indicating that fennel yield continued to improve over time. The linear trend equation y=0.0234x45.578 estimates that fennel yield increased by about 0.023 tonnes per hectare

per year during the study period. The coefficient of determination (R2 = 0.7028) indicates that nearly 70.28 percent of the variation in productivity is explained by the time trend, indicating a relatively strong upward trend in productivity.

This structural feature has important policy implications: it suggests that the low-hanging fruit of horizontal expansion may be approaching its agronomic and land-resource limits, particularly in the water-scarce districts of Gujarat and Rajasthan, making a shift towards a productivity-led growth model an imperative for the sector's long-term sustainability. The low coefficient of variation for productivity (0.17) relative to area (0.66) and production (0.78) confirms that yield levels are relatively stable across years.

Table 5. Descriptive statistics and CAGR of area, production and productivity of fennel crop in India (1994-95 to 2023-24)

S. No.	Variable	Area	Production	Productivity
1	Mean	59.62	90.79	1.41
2	SD	40.47	72.81	.24
3	CV	0.66	0.78	0.17
4	CAGR	6.89	8.73	1.69

Source: Researcher's computation

Table 5 presents a comprehensive analysis of fennel cultivation in India from 1994-95 to 2023-24, detailing descriptive statistics and Compound Annual Growth Rate (CAGR) for area, production, and productivity. The average area cultivated was 59.62 thousand hectares, yielding an average production of 90.79 thousand metric tonnes and an average productivity of 1.41 MT per hectare. Variability, as indicated by standard deviation, was highest in production (72.81), followed by area (40.47), and lowest in productivity (0.24). The coefficient of variation further underscored this, with production showing the highest instability (0.78), while productivity remained relatively stable (0.17).

Analysis of CAGR reveals a positive growth trajectory for all metrics. Area increased by 6.89% annually, production by 8.73%, and productivity by 1.69%. The substantial growth in production, exceeding the growth in area and productivity individually, suggests that both the expansion of cultivation area and enhancements in yield contributed to the overall increase in Indian fennel output. This indicates a steady expansion of fennel cultivation, supported by moderate productivity gains and increased land allocation.

From a policy standpoint, the dominance of area growth as the primary engine of production expansion aligns with the historical pattern observed by Kumawat and Meena (2005) but also raises concerns about the long-term feasibility of sustaining this trajectory given the finite availability of suitable semi-arid lands. Economically, the period between 2010 and 2019 represents the most structurally dynamic phase, characterized by the entry of large-scale commercial farmers, rising export realizations, and the mainstreaming of fennel within formal agribusiness supply chains. Collectively, these findings suggest that India's fennel sector is at a structural inflection point, where sustaining long-term growth will require a deliberate transition from area-led to productivity-led expansion, supported by investments in technology dissemination, value chain infrastructure, and market stabilization mechanisms.

The study's reliance on secondary data from official sources introduces potential limitations regarding data quality and consistency. The use of Compound Annual Growth Rate (CAGR) for long-term projections is constrained by its assumption of smooth growth, neglecting sector volatility. Furthermore, the absence of primary data collection limits nuanced insights into farmer-level constraints and practices. External factors like climate variability and policy shifts are not integrated, and the focus on aggregate trends may obscure crucial regional disparities in fennel cultivation.

5. Conclusion

This study analyzed the growth trends of fennel (*Foeniculum vulgare* Mill.) in India over a 30-year period (1994-95 to 2023-24), examining area, production, and productivity using secondary data and statistical analysis. The findings indicate a significant positive trend in all three dimensions (Bhusanar, et al., 2022). Area under cultivation exhibited a Compound Annual Growth Rate (CAGR) of 6.89%, with regression analysis

showing that time explains approximately 78% of the variation. Fennel production demonstrated a robust CAGR of 8.73%, with time accounting for about 84% of the variation in production. Productivity also showed a positive trend, with a CAGR of 1.69% and time explaining around 70% of the variation. The average area cultivated was 59.62 thousand hectares, resulting in an average production of 90.79 thousand metric tonnes and an average productivity of 1.41 MT per hectare. While production exhibited the highest variability (coefficient of variation: 0.78), productivity remained relatively stable (coefficient of variation: 0.17). The substantial growth in production, surpassing the individual growth rates of area and productivity, suggests a combined effect of increased cultivation area and improved yields. This points to a steady expansion of fennel cultivation in India, supported by moderate productivity enhancements and increased land allocation. Given the favorable market prices for fennel, it is recommended to educate farmers on its export potential, contract farming, and futures trading opportunities. Establishing grading and standardization infrastructure is also crucial to enable farmers to maximize returns from high-quality fennel production (Choudhary & Kharkwal 2023).

Disclaimer (Artificial Intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

Competing Interests

Authors have declared that no competing interests exist.

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