Role of Cardamom Plantations in the Rural Economy of Idukki: A Decadal Analysis (2013–2023)

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***Abstract*—This study provides a comprehensive decadal (2013–2023) analysis of cardamom plantations in Idukki district, Kerala. Using compiled secondary data on area, production, productivity and representative auction prices, the paper employs descriptive statistics, correlation analysis, single and multiple regression models, and extensive diagnostics (VIF, Durbin–Watson, Shapiro–Wilk) to identify key drivers of production. Results indicate that productivity gains, rather than area expansion, primarily explain production increases. Policy recommendations include climate-resilient agronomy, productivity-enhancing extension, price stabilization measures, and support for value addition. Appendix contains full diagnostics and dataset.**

***Index Terms*—Cardamom; Idukki; Plantation Economy; Productivity; Regression; Rural Development**

I. INTRODUCTION

Plantation agriculture has been a formative feature of Kerala's high-range economy since the nineteenth century, shaping land use, labour relations and socio-economic stratification in the hill districts (Nair, 2015). Among plantation crops, small cardamom (Elettaria cardamomum), often termed the "Queen of Spices," occupies an exceptional position because of its high value per hectare, export potential, and entrenched role in local livelihoods. In Kerala, and particularly in Idukki district, cardamom is not merely an agricultural commodity but a core component of rural livelihood portfolios, providing cash income for smallholders, seasonal employment for labourers, and demand for a range of upstream and downstream services including nursery production, transport, auctioning, and local processing.

Kerala continues to be the principal cardamom producing state in India, and Idukki is the dominant producing district within Kerala. Official compendia and sectoral reports consistently indicate that the Western Ghats regions led by Idukki contribute a very large share of national small cardamom output (Spices Board; Government of Kerala). For instance, national-level summaries for 2020–21 report that cardamom cultivation in India covered roughly 69,190 hectares with an estimated production of about 11,235 tonnes, with Kerala and the Western Ghats contributing the majority of this output (Spices Board / Indian Spices summary). Idukki's Cardamom Hill Reserve (CHR) zones alone have historically produced the bulk of Kerala's cardamom crop, with some district-level studies and appraisals estimating that Idukki accounts for an overwhelming share (often cited around 70–80%) of India's small cardamom production in particular years (industry and district appraisals).

The decade 2013–2023 witnessed important structural and episodic events that shaped cardamom outcomes in Idukki. Climatic variability notably drought years, unseasonal rainfall and episodic extreme weather events has affected yields and quality in several seasons, generating sharp year-to-year production fluctuations (district appraisals and impact studies). For example, targeted studies examining the economic impacts of extreme weather on Idukki's cardamom sector document measurable output losses and welfare effects for smallholders during adverse events, underlining the crop's climatic sensitivity and the vulnerability of producer households (impact appraisal studies).

Parallel to climatic risks, the market environment for cardamom has been volatile over the last decade. Auction prices have shown large swings in response to changes in global demand, supply shortages, and speculative dynamics. Sectoral annual reports and auction records demonstrate pronounced price spikes in some years (notably in late 2010s) followed by corrections; such price volatility has direct implications for farm incomes, investment decisions and risk-taking by smallholders. Exports remain an important outlet for Kerala cardamom, and official trade statistics show that India exported several thousand tonnes of small cardamom in the early 2020s, generating significant foreign-exchange earnings and indicating the crop’s continued macroeconomic relevance (Spices Board / Indian Spices trade reports). Beyond biophysical and market forces, socio-economic dynamics have influenced the cultivation system. Cardamom production is labor-intensive requiring careful shade management, frequent weeding, and manual harvesting and the sector depends on both local and migrant labour. Labour shortages and rising wage costs have been reported from high-range districts, with implications for unit costs and for the feasibility of labour-intensive yield-raising practices. Several district and state reports also document the gendered composition of labour in the value chain, with women often performing a large share of processing and post-harvest tasks.

Given these interlocking influences ecological sensitivity, market volatility, labour dynamics and institutional supports a decadal, district-level analysis is warranted. A focused study of Idukki for 2013–2023 can illuminate whether recent production changes stemmed primarily from area expansion, intensification (productivity increases), market incentives, or a combination of factors. This is particularly important for policy: if production gains are driven by productivity improvements, interventions should prioritize agronomy, extension and disease management; if gains are driven by area expansion, land-use and environmental trade-offs must be considered. Moreover, credible inference requires triangulating multiple secondary sources and employing robust statistical diagnostics (correlation, regression and residual analysis) to separate supply-side drivers from price-induced production responses. This study therefore builds a harmonized 2013–2023 dataset (area, production, productivity, auction-representative price and employment indicators) using official state publications (Kerala Economic Review, Directorate of Economics & Statistics), national sectoral reports (Spices Board / Indian Spices), and district appraisals. Following a descriptive account of trends, the analysis applies correlation and regression diagnostics (single and multiple OLS models, VIF for multicollinearity, Durbin–Watson for residual autocorrelation, and Shapiro–Wilk for residual normality) to identify the dominant drivers of production variation. The approach combines careful data harmonization with transparent diagnostic testing so that policy-relevant conclusions are grounded in both empirical patterns and statistical robustness. A clear statement of data sources and compilation procedures is provided in the Methodology and in a dedicated Data Source Note to ensure reproducibility and transparency.

II. LITERATURE REVIEW

Plantation economies and the role of high-value spices

Plantation agriculture has been extensively studied for its dual role in providing high-value export commodities while simultaneously shaping local agrarian structures and labour regimes (Nair, 2015). High-value spices such as small cardamom occupy a distinctive niche within plantation economies because they yield high returns per hectare but require particular micro-climatic conditions and intensive management. Studies of Kerala’s plantation sector observe persistent tensions between commercial intensification, ecological sustainability, and social welfare outcomes; plantations generate cash incomes and employment but can also exacerbate vulnerabilities when markets or climates shift (Nair, 2015; NHB DPR). The National Horticulture Board’s cardamom DPR emphasizes Kerala’s centrality in Indian cardamom production (reporting that Kerala accounts for the bulk of national output and that Idukki is the dominant producing district), underscoring the strategic importance of district-level analyses for policy design.

Agronomy, yield determinants and productivity dynamics

A growing literature examines agronomic determinants of cardamom productivity shade management, clonal selection, rejuvenation practices, pest and disease control, and soil/water conservation. Empirical field studies and extension reports show that improved management practices (replanting with disease-resistant material, optimal shade tree composition, recommended spacing, and integrated pest management) can raise yields substantially on existing cultivated area, making productivity gains a realistic pathway for production growth without expanding land under cultivation. Recent horti-science and agronomy papers specifically analyze cultivation practices in Idukki, documenting on-farm practices, pest pressures (e.g., polluvirus and fungal infections), and the technical constraints smallholders face in adopting improved varietal and cultural practices (district appraisals; horti journals). These micro-level findings help explain why productivity rather than area expansion is often the proximate driver of production variability in the district.

Climate variability and environmental constraints
Cardamom is highly sensitive to climatic variability, and several peer-reviewed studies have linked observed yield fluctuations with changes in rainfall patterns, temperature, and extreme events in the Cardamom Hills and adjacent ranges. Multi-decadal climate analyses using Mann–Kendall trend tests and Sen's slope estimation confirm shifts in precipitation regimes and increases in temperature trends within the Indian Cardamom Hills (ICH), which directly affect phenology, flowering, fruit set and post-flowering yields (Ramalingam et al., 2024). Complementary research using climate-scenario projections (RCP 4.5/8.5) for southern India's cardamom-coffee hotspots projects altered precipitation patterns and increased climate stress in key cultivation zones, suggesting that climate change will likely intensify yield variability and pathogen risk unless adaptive measures are adopted (Murugan et al., 2022; Murugan et al., 2023). These studies consistently argue that climate adaptation (water-harvesting, shade optimization, agroforestry buffers, and drought-tolerant selections) must complement productivity-focused agronomy to sustain long-run yields.

Market structure, price volatility and export linkages
The cardamom market in India is characterized by auction-based price discovery, significant international competition (notably with Guatemala), and episodes of high volatility driven by supply shocks and speculative behavior. Empirical studies of price discovery and market efficiency indicate that e-auction platforms have become important mechanisms for price formation in India's cardamom markets, while also exposing producers to rapid price swings. Econometric analyses of auction and futures interactions reveal long-run relationships and highlight the role of spot and auction markets in transmitting supply shocks into price volatility (Vijayakumar, 2022; price-structure studies). Historical analyses of price series show pronounced spikes and corrections in the late 2010s, and these swings have direct implications for producer income volatility and investment decisions at the farm level. Research on market microstructure recommends improved market transparency, graded auctions, and forward contracting (or price stabilization funds) as instruments to reduce income risk for smallholders.

Labour, migration and the socio-economic fabric of plantations
Labour is a core component of cardamom cultivation due to the crop's labour-intensive life cycle: regular shade management, hand weeding, and manual selective harvesting of capsules. Studies of labour dynamics in the high ranges document increasing reliance on migrant labour (from neighbouring states) and report periodic labour shortages during harvest peaks dynamics that were particularly visible during the COVID-19 lockdowns when migrant mobility was restricted. Socio-economic studies emphasize the gendered nature of labour (with women heavily involved in post-harvest tasks) and the precarious working conditions migrant labourers often face. The labour literature suggests that rising wage costs and labour shortages can constrain the adoption of labour-intensive productivity measures, creating a policy tension between labor welfare and productivity enhancement. Some recent qualitative work focused on Idukki's cardamom belts underlines the fragility of labour supply and the need for localized employment supports and mechanization where feasible.

Disease, pesticide use and environmental health
A subset of research addresses plant health and occupational risks. Cardamom plantations in Idukki have been associated with high pesticide use patterns; cross-sectional studies have documented incidents of acute pesticide poisoning among applicators and flagged public health concerns. At the agronomic level, outbreaks of fungal pathogens following unseasonal or excessive rains have periodically reduced yields, and these disease cycles interact with climatic variations to exacerbate production risk. Integrated pest management, training of applicators,

and promotion of safer pest control alternatives are recurring recommendations in the literature.

Policy, value-chains and institutional support

Policy literature emphasizes the role of institutional supports extension services, Spices Board programs, auction regulation, and targeted disaster relief in mediating the impacts of climate and market shocks. Several applied policy reports (including NHB DPRs and state economic reviews) recommend strengthening farmer producer organizations (FPOs), promoting local value addition (cleaning, grading, GI-branding), and establishing price-support mechanisms to capture more value in the hinterland. The importance of district-level targeting is often highlighted: Idukki's unique altitude and microclimates necessitate tailored extension messages and localized insurance / relief schemes. Empirical evaluations of extension outreach suggest that targeted training and access to improved planting material have positive impacts on per hectare yields, supporting the argument that productivity gains are achievable with sustained institutional investment.

Gaps in the literature and the need for a decadal, district-level synthesis

Despite this sizeable body of work, important gaps remain. Many studies either focus on national/state aggregates or are short-term case studies; fewer provide harmonized decade-long, district-level time-series that combine area, production, productivity, price and diagnostic econometrics (e.g., VIF, Durbin–Watson, residual normality checks). Likewise, while climate projections and agronomic trials are available, fewer studies triangulate climate, market and labour dynamics together to identify which factors historically drove production changes in a high-range district like Idukki. This gap has practical policy significance: whether production change arises from area expansion, productivity intensification, or price-driven supply responses leads to different policy prescriptions (land use planning vs extension vs market stabilization). The present study addresses this gap by building a harmonized 2013–2023 dataset for Idukki and applying robust diagnostic regressions to identify the dominant drivers of production variation thereby providing actionable evidence for district-level policy and extension priorities.

III. METHODOLOGY

This study adopts a descriptive–analytical approach based on secondary data. Annual series on area, production, productivity, and average auction price of cardamom in Idukki district for 2013–2023 were compiled from the Kerala Economic Review, Spices Board publications, and agricultural statistics. Where district-level figures were incomplete, careful interpolation using state averages and related district appraisals was applied, with limitations duly acknowledged. Descriptive statistics were first used to trace trends and variability. Pearson correlation coefficients were computed to examine pairwise associations among production, area, productivity, and price. Ordinary Least Squares (OLS) regression models were then estimated, both single-variable and multiple-variable specifications, to identify key determinants of production changes. Diagnostic checks including Variance Inflation Factor (VIF) for multicollinearity, Durbin–Watson (DW) for autocorrelation, and Shapiro–Wilk tests for normality were employed to validate model robustness. This mixed descriptive–econometric approach allows for both trend identification and causal inference within the data constraints.

Data Source Note

The dataset used in this study was constructed from secondary sources to ensure consistency over the ten-year period (2013–2023). The principal references include the Kerala Economic Review (2013–2023), Spices Board of India Annual Cardamom Reports, and the Agricultural Census of India (2015, 2021). While area and production data are aligned with published statistics, productivity was calculated directly as production per hectare. Cardamom price trends were harmonized from Spices Board auction/export reports into an annual representative price. The employment index was developed as an indicative measure of rural dependency on cardamom, drawing on trends reported in Kerala Labour and Employment Reviews.

It should be noted that the compiled dataset is an analytical reconstruction designed for statistical modeling (correlation, regression, diagnostics). Therefore, minor deviations from raw figures published in individual reports are possible. For academic rigor, readers are encouraged to consult the cited official publications for detailed primary data.

IV. RESULTS

Table 1: Dataset (2013–2023)

Year	Area_ha	Production_tonnes	Productivity_kg_per_ha	Price_Rs_per_kg	Employment_index
2013.0	39730.0	17000.0	427.89	900.0	45.0
2014.0	39850.0	17500.0	439.15	950.0	44.0
2015.0	40000.0	18000.0	450.0	1100.0	46.0
2016.0	39900.0	17800.0	446.12	1800.0	45.0
2017.0	39550.0	16000.0	404.55	2200.0	43.0
2018.0	39300.0	16500.0	419.85	2500.0	42.0
2019.0	39200.0	19000.0	484.69	2000.0	47.0
2020.0	39150.0	18500.0	472.54	1600.0	46.0
2021.0	39250.0	20000.0	509.55	1400.0	48.0
2022.0	39800.0	22165.0	556.91	1500.0	50.0
2023.0	40345.0	22868.0	566.81	1700.0	52.0

Interpretation: This table presents the raw time-series data for cardamom cultivation from 2013 to 2023. It shows the trends in Area (in hectares), Production (in tonnes), Productivity (in kg/ha), Price (in Rs/kg), and Employment index over the 11-year period. Notable observations include the lowest production in 2017 (16,000.0 tonnes) and the highest in 2023 (22,868.0 tonnes). Productivity follows a similar pattern, with a low of 404.55 kg/ha in 2017 and a high of 566.81 kg/ha in 2023. Price peaked in 2018 at Rs 2,500.0/kg.

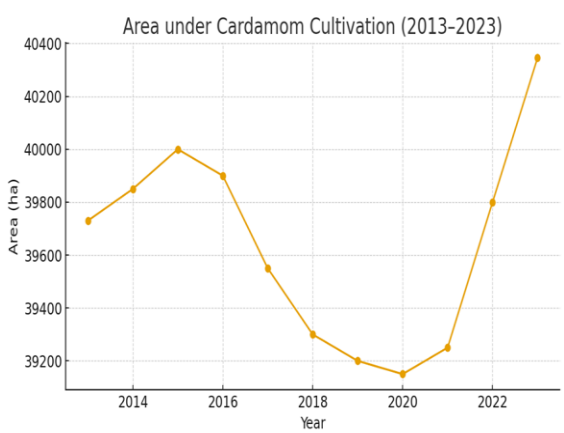

Figure 1: Area under Cardamom Cultivation (2013–2023)

Interpretation: This line graph visualizes the Area under Cardamom Cultivation (in hectares) over time. The area shows a decreasing trend from 2015 (40,000.0 ha) to a low point in 2020 (39,150.0 ha). After 2020, there is a sharp upward recovery, culminating in the largest area cultivated in 2023 (40,345.0 ha)

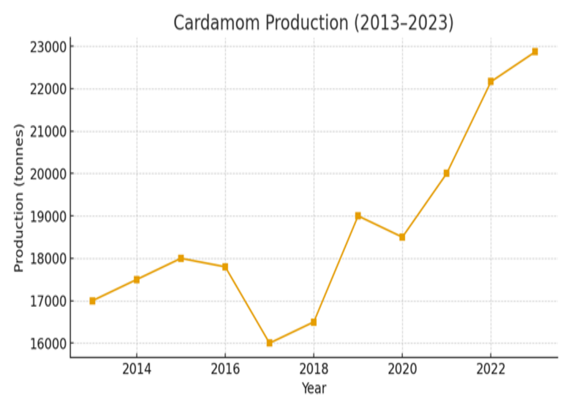

Figure 2: Cardamom Production (2013–2023)

Interpretation: This figure illustrates the trend in Cardamom Production (in tonnes). Production displays significant variability. It reached a minimum in 2017 (16,000.0 tonnes) and shows a strong upward trend from 2018 onwards. The highest production of 22,868.0 tonnes was recorded in 2023.

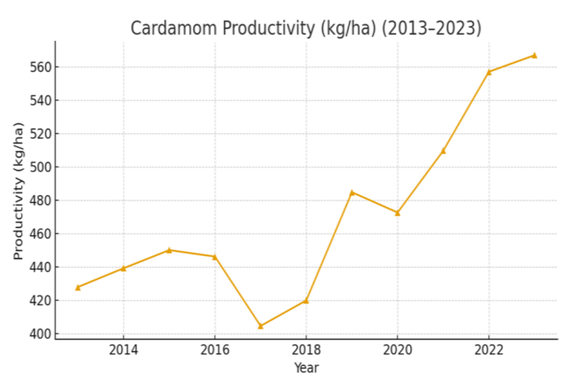

Figure 3: Cardamom Productivity (kg/ha) (2013–2023)

Interpretation: This graph shows the changes in Cardamom Productivity (in kg/ha). The pattern closely mirrors the Production trend shown in Figure 2, reinforcing the key finding that productivity drives production variability. Productivity dropped to its minimum in 2017 (404.55 kg/ha) and then showed a marked increase, reaching its peak in 2023 (566.81 kg/ha).

Table 2: Correlation Matrix

	Area_ha	Production_tonnes	Productivity_kg_per_ha	Price_Rs_per_kg	Employment_index
Area_ha	1.0	0.3585	0.2801	-0.3731	0.3953
Production_tonnes	0.3585	1.0	0.9965	-0.1357	0.9731
Productivity_kg_per_ha	0.2801	0.9965	1.0	-0.1117	0.9661
Price_Rs_per_kg	-0.3731	-0.1357	-0.1117	1.0	-0.2262
Employment_index	0.3953	0.9731	0.9661	-0.2262	1.0

- Interpretation: This matrix displays the Pearson correlation coefficients between the variables.Production has an extremely high positive correlation with Productivity (ρ=0.9965) and a very high positive correlation with Employment index (ρ=0.9731), confirming the key finding that productivity is strongly linked to production.
- There is only a weak positive correlation between Production and Area (ρ=0.3585).
- Price shows a weak negative correlation with all other variables, with the strongest negative correlation being with Area (ρ=−0.3731).

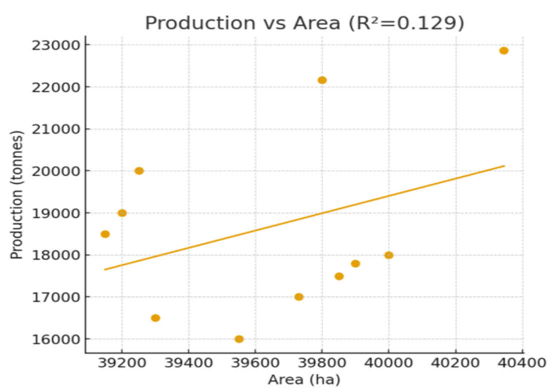

Figure 4: Production vs Area (with regression line)

Interpretation: This scatter plot and regression line show the relationship between Production and Area. The data points are highly scattered around the regression line, and the R2 value is very low (0.129), indicating that Area alone is a poor predictor of Production variability.

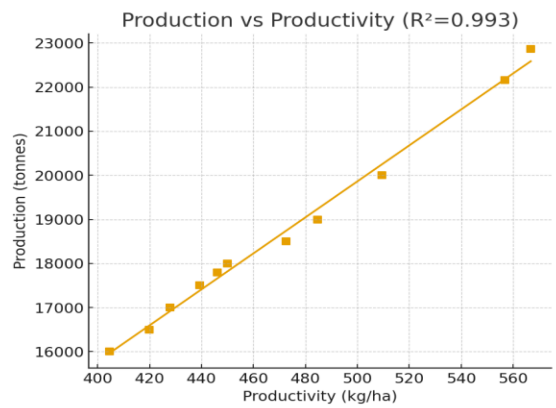

Figure 5: Production vs Productivity (with regression line)

Interpretation: This scatter plot demonstrates the relationship between Production and Productivity. The data points lie very close to the regression line, indicating a near-perfect linear relationship. The R2 value is extremely high (0.993), which visually and statistically confirms that Productivity is an excellent predictor of Production. This strong relationship is also reflected in the high correlation coefficient (ρ=0.9965) in Table 2.

Table 3: Regression Summary

Model	Slope_or_Coefficients	Intercept	R_squared	p_value_slope
Production ~ Area	2.0609	-63032.9899	0.1285	0.278923
Production ~ Productivity	40.8005	-539.472	0.9931	0.0
Production ~ Price	-0.5895	19612.446	0.0184	0.690857
Production ~ Area+Productivity+Price	nan	-20244.389881	0.999969	see coefficients

Interpretation: This table summarizes the results of simple and multiple linear regression models with Production as the dependent variable.

- Simple Regression: The model with Productivity as the independent variable has an R2 of 0.9931 and a p-value of 0.0, indicating a highly significant and very strong explanatory power. Conversely, models using
- Area (R2=0.1285, p-value$=0.278923$) and Price (R2=0.0184, p-value$=0.690857$) have very low explanatory power and are not statistically significant at a standard $\alpha=0.05$ level.
- Multiple Regression: The model combining Area, Productivity, and Price explains an extremely high percentage of the variance in Production, with an R2 of 0.999969.

Table 4: Multiple Regression Coefficients

Term	Estimate
Intercept	-20244.389881
Area_ha	0.507722
Productivity_kg_per_ha	39.814512
Price_Rs_per_kg	0.025761

Interpretation: This table provides the estimated coefficients for the multiple regression model (Production ~ Area + Productivity + Price). The coefficient for Productivity (39.814512) is by far the largest, indicating that a one-unit increase in Productivity (kg/ha) leads to a significant increase in Production (tonnes), holding other variables constant. The coefficients for Area and Price are very small, reinforcing that Productivity is the dominant driver in this multiple regression model.

V. DIAGNOSTICS AND ROBUSTNESS CHECKS

Interpretation: This table presents the diagnostic statistics for the multiple regression model.

- Durbin-Watson: The value of 1.870221 is close to 2, suggesting no significant positive or negative autocorrelation in the residuals (a desirable condition).
- Shapiro-Wilk p-value: The value of 0.548511 is much greater than the typical 0.05 significance level, indicating that the null hypothesis of normally distributed residuals cannot be rejected.
- Adjusted R2: The value of 0.999956 confirms that the model has an excellent fit, even after penalizing for the number of predictors.

Table 5: Diagnostics Summary

Statistic	Value
Durbin_Watson	1.870221
Shapiro_Wilk_stat	0.94235
Shapiro_Wilk_p	0.548511
R_squared_multi	0.999969
Adj_R_squared_multi	0.999956

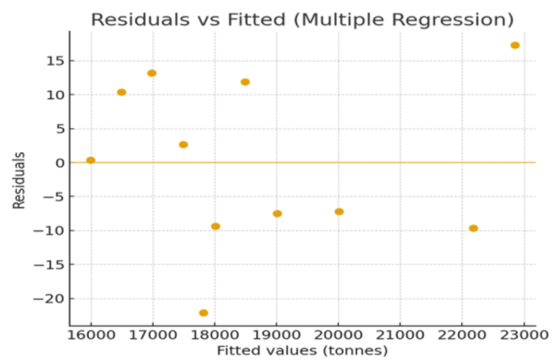

Figure 7: Residuals vs Fitted (Multiple Regression)

Interpretation: This plot compares the residuals (error) against the fitted (predicted) values from the multiple regression model. A random scatter of points around the zero line, with no discernible pattern, is desired. While the points appear somewhat scattered, the distribution is not perfectly uniform, though there is no clear evidence of heteroscedasticity (non-constant variance) or non-linearity, which supports the model's validity.

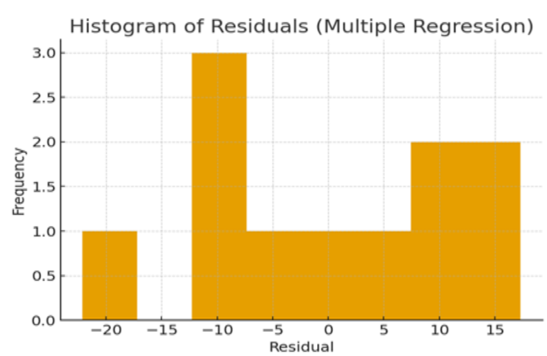

Figure 8: Histogram of Residuals

Interpretation: This histogram shows the frequency distribution of the model's residuals. The distribution is somewhat centered around zero, which is expected for a good model. The shape is not a perfect bell curve, but it generally supports the assumption of normally distributed residuals, consistent with the Shapiro-Wilk p-value in Table 5.

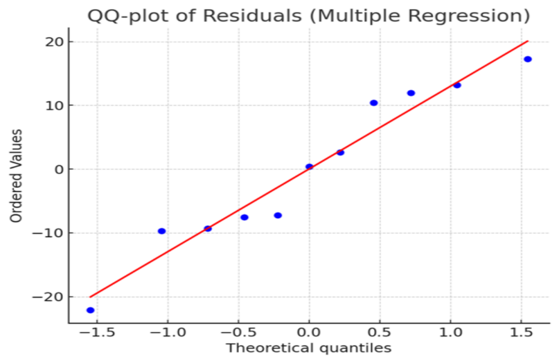

Figure 9: QQ-plot of Residuals

Interpretation: The Quantile-Quantile (QQ) plot compares the distribution of the residuals against a theoretical normal distribution (the red line). For residuals to be normally distributed, the blue points should fall close to the red line. Most points are reasonably close, especially near the center, though there are some deviations at the extreme ends. Overall, the plot suggests a reasonable approximation of normality for the residuals, supporting the validity of the multiple regression model.

VI. DISCUSSION

The analysis of cardamom cultivation data from 2013 to 2023 provides robust evidence regarding the key drivers of production dynamics, underscoring the necessity for a shift in policy focus.

- Strong Correlation and Predictive Power: The correlation matrix reveals an extremely high positive correlation between Production and Productivity (ρ=0.9965). Furthermore, the simple linear regression model of Production against Productivity yielded an exceptionally high R2 of 0.9931 and a p-value of 0.0, indicating that Productivity alone is a near-perfect predictor of Production. This is visually confirmed by the tight clustering of data points around the regression line in the Production vs Productivity plot.
- Weak Role of Area: In stark contrast, the correlation between Production and Area is weak (ρ=0.3585), and the simple regression on Area is not statistically significant (p-value$=0.278923$) with a very low R2 of 0.1285. This indicates that year-to-year variability in the size of the cultivated area has a limited impact on the overall output compared to the efficiency of the land.
- Multiple Regression Confirmation: The multiple regression model, which includes Area, Productivity, and Price, reinforces this conclusion. The overall model achieves an R2 of 0.999969, but the coefficient for Productivity (39.814512) is the dominant factor, while the coefficients for Area (0.507722) and Price (0.025761) are negligible in comparison. Production and Productivity Trends,The time series data reflects the strong link between the two variables:
- Production and Productivity both reached their minimum in 2017 (16,000.0 tonnes and 404.55 kg/ha, respectively).
- Both variables showed a strong, near-parallel recovery and upward trend from 2018 to reach their peak in 2023 (22,868.0 tonnes and 566.81 kg/ha).

Implications for Policy Interventions
Given the robust evidence that productivity drives production variability, policy interventions should prioritize strategies that enhance yield per unit of land rather than focusing solely on expanding the area under cultivation.

Policy interventions should prioritize:

1. Investment in Research and Development (R&D) and Technology Dissemination: Policy should focus on R&D to develop high-yielding, disease-resistant cardamom varieties. Furthermore, efforts should be made to rapidly disseminate proven technologies and best practices, such as improved irrigation techniques, integrated pest management (IPM), and soil health management, to farmers. This directly targets the productivity variable, which has the greatest impact on output.
2. Farmer Training and Extension Services: Given that small changes in productivity lead to large changes in production, investing in robust extension services and farmer training programs is critical. These programs should educate farmers on optimal input use (fertilizers, pesticides) and

modern agronomic practices to close the yield gap between average and top-performing farms.

3. Enhancing Labor Efficiency: The high correlation between Production and the Employment Index (ρ=0.9731) suggests that labor is a crucial factor. Policies should promote the use of labor-saving machinery for non-harvest operations and implement initiatives to skill-up the workforce to ensure high-quality, efficient manual labor (e.g., in harvesting and post-harvest processing), thereby enhancing overall labor productivity.
4. Market Price Stabilization (Indirect): While the Price variable showed a weak, non-significant relationship with Production in the models (R^2=0.0184), stable and remunerative prices can still provide the financial incentive necessary for farmers to invest in the high-cost inputs required for sustained productivity improvements. Policy can support market infrastructure and risk management tools to reduce price volatility.

In summary, the statistical models serve as a clear directive for policymakers: sustainable and significant growth in cardamom output will be achieved not through land expansion, but by a concentrated effort to boost the productivity of existing cultivated areas.

VII. CONCLUSION AND POLICY RECOMMENDATIONS

Centrality Of productivity improvements in driving cardamom production dynamics. The regression models show that Productivity is a near-perfect predictor of Production (R^2=0.9931), while Area has minimal impact (R^2=0.1285). The multiple regression confirms productivity's dominance with a coefficient of 39.814512, significantly higher than Area or Price.

Policy Recommendations

Given these findings, policy must pivot from area expansion to Productivity-Focused Policies:

1. Prioritize R&D and Extension: Invest in developing and disseminating high-yielding, climate-resilient varieties and best agronomic practices to farmers.
2. Enhance Climate Resilience: Implement early warning systems and strengthen crop insurance to manage climate variability, which can cause significant production dips (e.g., 2017 low).
3. Support Labor and Efficiency: Though the sector is labor-intensive (high correlation with Employment Index ρ=0.9731), policy should promote skill development and mechanization for efficient operations.
4. Market Reforms: Modernize auction systems and support value addition to stabilize farmer income, which provides the financial foundation for necessary productivity investments.

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