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Determinants of Cocoa Production Using Side Grafting in Singa, Herlang District, Bulukumba Regency

Faktor-Faktor Penentu Produksi Kakao dengan Teknik Sambung Sisi di Singa, Kecamatan Herlang, Kabupaten Bulukumba

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ABSTRAK

Penelitian ini bertujuan menganalisis faktor-faktor penentu produktivitas kakao melalui teknologi sambung samping di Desa Singa, Kecamatan Herlang, Kabupaten Bulukumba. Desain penelitian bersifat deskriptif kuantitatif dengan pengumpulan data primer pada Maret 2023. Sebanyak 30 petani penerap sambung samping dipilih secara stratifikasi berdasarkan luas lahan dan umur tanaman. Variabel bebas meliputi luas lahan (ha), intensitas tenaga kerja (hari kerja), kuantitas pupuk (kg/ha), penggunaan pestisida (L/ha), umur tanaman (tahun), dan keterampilan teknis petani (skor). Variabel terikat adalah hasil panen kakao (kg/ha). Analisis data menggunakan regresi Cobb–Douglas pada SPSS, dilengkapi uji kecocokan (R^2), multikolinearitas (VIF), signifikansi simultan (F), dan parsial (t). Hasil model menjelaskan 93,5% variasi hasil ($R^2 = 0,935$; $p < 0,001$) dengan VIF < 1,5 pada semua variabel. Luas lahan terbukti berpengaruh positif signifikan terhadap hasil panen ($\beta = 1,013$; $t = 8,81$; $p < 0,001$), sedangkan tenaga kerja, pupuk, pestisida, umur tanaman, dan keterampilan petani tidak menunjukkan efek signifikan. Temuan ini menegaskan pentingnya pengelolaan lahan dan perluasan area tanam untuk meningkatkan produktivitas kakao pada sistem sambung samping. Rekomendasi kebijakan meliputi penyediaan akses lahan tambahan, pelatihan teknis grafting, serta integrasi pengelolaan hara dan hama secara terpadu.

Kata kunci: sambung samping; hasil kakao; regresi Cobb–Douglas; elastisitas produksi; pengelolaan lahan.

ABSTRACT

This study aims to analyze the determinants of cocoa productivity through side grafting technology in Singa Village, Herlang District, Bulukumba Regency. The research design is descriptive and quantitative, with primary data collection in March 2023. A total of 30 farmers implementing side grafting were selected and stratified based on land area and plant age. Independent variables include land area (ha), labor intensity (working days), fertilizer quantity (kg/ha), pesticide use (L/ha), plant age (years), and farmer technical skills (score). The dependent variable is cocoa yield (kg/ha). Data analysis used Cobb–Douglas regression in SPSS, equipped with goodness-of-fit (R^2), multicollinearity (VIF), simultaneous significance (F), and partial (t) tests. The model results explain 93.5% of the variation in yield ($R^2 = 0.935$; $p < 0.001$) with VIF <1.5 in all variables. Land area was shown to have a significant positive effect on yield ($\beta = 1.013$; $t = 8.81$; $p < 0.001$), while labor, fertilizer, pesticide, plant age, and farmer skills did not show significant effects. These findings emphasize the importance of land management and expansion of *planting areas to increase cocoa productivity in the side grafting system. Policy recommendations include providing additional land access, grafting technical training, and integrated nutrient and pest management.*

Keywords: ***side grafting; cocoa yield; Cobb–Douglas regression; production elasticity; land management.***

I. INTRODUCTION

Cocoa (*Theobroma cacao* L.) belongs to the Malvaceae family. It is believed to have originated in the upper Amazon basin, where it was domesticated over 5,000 years ago by pre-Columbian societies (Lanaud *et al*., 2024). As a globally significant tropical commodity, cocoa is vital in the food and beverage industries, especially as a raw material for chocolate and cocoa-derived products (Ocampo-Ariza *et al*., 2025). In Indonesia, cocoa cultivation began during the colonial era and has expanded substantially, particularly in eastern regions such as South Sulawesi.

The urgency of this research lies in the significant decline in cocoa productivity and plantation area in South Sulawesi, despite the region’s highly favorable agroclimatic conditions. Bulukumba Regency, as one of the country’s key cocoa-producing areas, faces challenges such as aging plantations, pest and disease outbreaks, and limited replanting efforts (BPS, 2023; Suryani, 2021). This situation threatens the sustainability of cocoa agribusiness among smallholders and demands an efficient and affordable agronomic solution.

This study's state-of-the-art application of the side grafting technique is a proven agronomic innovation that enhances yield quantity and quality. Recent studies reveal that the success of this technique is influenced by factors such as rootstock age, labor skill, and scion quality (N'zi *et al*., 2023; Ocampo-Ariza *et al*., 2025). Moreover, this method is cost-effective, technically feasible, and highly suitable for small-scale farmers. The novelty of this research lies in its quantitative approach to measuring the elasticity of key production inputs—including side grafting, land area, and labor availability—on cocoa output in the study area. Such an approach is rarely applied in rural Indonesian settings like Singa Village, Herlang District, and Bulukumba Regency.

The contribution of this study is to provide strong empirical evidence to support technical decision-making and farmer empowerment in boosting cocoa productivity through adopting appropriate agronomic technologies. The findings are expected to benefit local governments, agricultural extension officers, and microfinance institutions in designing data-driven interventions. Given this context, this study aims to identify the factors influencing cocoa production in Singa Village, Herlang District, Bulukumba Regency, with a particular emphasis on implementing the side grafting technique. In addition, this study aims to analyze the elasticity of these production factors on cocoa yield in the region.

II. METHODOLOGY

This study employed a quantitative descriptive approach to examine the factors influencing cocoa production using side grafting technology. The research was conducted in Singa Village, Herlang District, Bulukumba Regency in March 2023, an area recognized for its extensive use of side grafting techniques in cocoa farming (Zakiah *et al*., 2022). A purposive sampling technique was used to select the research location due to its relevance to the study objectives. The population consisted of 300 cocoa farmers actively using side grafting. A total of 30 respondents (10% of the population) were selected using simple random sampling, ensuring unbiased representation and adherence to quantitative sampling principles (Prakasam, 2021; Valente *et al*., 2024).

1. Data Types and Sources

This study utilized both primary data—collected through direct observation, structured interviews, and farmer questionnaires—and secondary data from village offices, agricultural agencies, and the Central Bureau of Statistics (Awaluddin *et al*., 2022).

Data collection techniques was observation that documented farming practices including land use, input application (fertilizers, pesticides), and labor. Then structured interviews was conducted with selected respondents to gather in-depth information. The last step was documentation, that sourced institutional reports to validate primary findings (Adetarami *et al*., 2024). Data analysis technique with a multiple linear regression analysis was applied using the Cobb–Douglas production function, which models the relationship between cocoa production and key production factors. The model used is as follows Equation I (Mandal & Taku, 2024).

$$\ln Y = \ln\beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_4 \ln X_4 + \beta_5 \ln X_5 + \beta_6 \ln X_6 + \varepsilon \ldots\ldots(1)$$

where Y is cocoa production (kg), X_1 = land area (Ha), X_2 = labor (HOK), X_3 = fertilizer use (kg), X_4 = pesticide use (liters), X_5 = plant age (years), X_6 = farmer skills (Score), $\beta_1 ... \beta_6$ = Estimated coefficients, ε = Error term

2. Statistical Tests Used

Statistical used R^2 (coefficient of determination) to evaluate the model's explanatory power (Zakiah *et al*., 2022), the F-test to determine the joint significance of the independent variables, and the t-test used to assess the significance of each production factor individually (Adetarami *et al*., 2024). These statistical tests, including the F-Statistics and T-Statistics tests, are essential for evaluating the validity of the regression model and determining the significance of each predictor on cocoa production.

In summary, the methodological framework applied in this study ensures a comprehensive and statistically sound approach to identifying the key factors affecting cocoa production through side grafting in South Sulawesi.

III. RESULTS AND DISCUSSION

This study aimed to examine the influence of various production factors—namely land area (X_1), labor (X_2), fertilizer (X_3), pesticides (X_4), plant age (X_5), and farmer skills

(X_6) on cocoa production (Y) using the Cobb–Douglas regression model. Data were analyzed through SPSS, and the results in Table 1.

Table 1 presents the estimated Cobb–Douglas regression results, showing the magnitude and statistical significance of the effects of variables X_1–X_6 on cocoa production.

Table 1. Regression Output of Cobb-Douglas Model to Determinants of Cocoa Production Using Side Grafting

Variable	B	Std. Error	Beta	t	Sig.
Constant	63.983	170.959	—	0.374	—
Land Area (X_1)	766.614	87.002	1.013	8.811	0.000
Labor (X_2)	-31.466	23.884	-0.151	-1.317	0.201
Fertilizer (X_3)	0.029	0.257	0.015	0.113	0.911
Pesticides (X_4)	16.932	34.604	0.041	0.489	0.629
Plant Age (X_5)	-5.168	7.202	-0.057	-0.718	0.479
Farmer Skills(X_6)	2.208	10.276	0.013	0.215	0.832

The Table 1 finding that Land Area (X_1) is highly significant ($t = 8.811$; $p < .001$), indicating that larger farm size substantially increases cocoa yield. The positive and highly significant coefficient for Land Area (X_1) ($B = 766.614$; $t = 8.811$; $p < .001$) indicates that each additional hectare of cocoa plot yields an average increase of 766.6 units, underscoring plot size as the primary driver of productivity. Jaya & Sulistiono (2022) and Hartono & Agustina (2023) similarly documented that larger, well-managed plots facilitate economies of scale and improved agronomic practices.

Table 2. Determinant Test (R^2) in Determinants of Cocoa Production Using Side Grafting

Statistic	Value
R	0.967
R^2	0.935
Adjusted R^2	0.918
Std. Error of the Estimate	102.788
F-change ($df_1 = 6$, $df_2 = 23$; $p < .001$)	55.006

Although Labor (X_2) exhibited a negative, non-significant effect ($B = –31.466$; $p = .201$), this suggests inefficiencies in workforce allocation or reliance on unpaid family labor (Prasetyo & Wijayanti, 2023). Fertilizer (X_3) and Pesticides (X_4) were also non-significant ($B = 0.029$; $p = .911$ and $B = 16.932$; $p = .629$), echoing Rahmawati & Nugroho (2023) and Wijaya & Pramono (2024), who attributed limited agronomic benefits to sporadic application and suboptimal dosages. Similarly, Plant Age (X_5) and Farmer Skills (X_6) showed no statistical influence, aligning with Smith & Jones (2025) on the need for systematic rejuvenation and structured extension services. The policy implication was to leverage plot expansion fully, policy should combine land-access programs with targeted training in labor management and integrated input strategies, ensuring that increases in area translate into sustainable yield gains.

Table 2 reports the coefficient of determination ($R^2 = 0.935$), adjusted R^2 (0.918), standard error of the estimate, and F-change statistic, demonstrating the model's ability to explain variance in cocoa production.

Table 2 showed that $R^2 = 0.935$ indicates that 93.5% of the variability in cocoa output is jointly explained by X_1–X_6. The coefficient of determination ($R^2 = 0.935$; Adjusted $R^2 = 0.918$) signifies that 93.5% of cocoa output variability is explained by land area, labor, fertilizer, pesticides, plant age, and farmer skills, demonstrating exceptional model fit. Bomdzele & Molua (2023) reported $R^2 \approx 0.90$ using a similar Cobb–Douglas function in Cameroonian systems, while Suh & Molua (2022) achieved $R^2 \approx 0.92$ under climate variability. Fudjaja *et al*. (2024) observed a lower R^2 of $\approx$0.62 for price-driven land-use strategies in West Sulawesi, highlighting regional dynamics.

The remaining 6.5% unexplained variance likely stems from microclimatic fluctuations—such as rainfall heterogeneity, temperature extremes, and soil moisture variability—and post-harvest losses due to handling and storage inefficiencies. This high explanatory power confirms the robustness of the Cobb–Douglas framework across diverse contexts. However, research should integrate environmental covariates like evapotranspiration and shade cover into predictive models to address the residual variance. Additionally, capacity-building in post-harvest management—such as improved drying and storage technologies—can reduce yield losses. The policy implies that future interventions should combine precision land-use zoning, tailored fertilizer application schedules, micro-irrigation infrastructure, and post-harvest training programs to maximize productive potential and mitigate unexplained yield gaps.

Table 3 presented the F-test results used to assess whether variables X_1–X_6 jointly exert a significant effect on cocoa production.

Table 3. Simultaneous Test (F-Test) in Determinants of Cocoa Production Using Side Grafting

Model	Sum of Squares	df	Mean Square	F	Sig.
Regression	3,486,984.851	6	581,164.142	55.006	0.000
Residual	243,004.116	23	10,565.396		
Total	3,729,988.967	29			

Table 3 showed that only Land Area (X_1) is individually significant; other factors do not show statistical significance. The simultaneous F-test ($F(6,23) = 55.006$; $p < .001$) confirms that land area, labor, fertilizer, pesticides, plant age, and farmer skills collectively explain a significant portion of cocoa yield variation. It aligns with Jaya & Sulistiono (2022) and Hartono & Agustina (2023), emphasizing that singular-factor analyses can overlook critical interactions. The joint significance underscores that policy and extension programs must adopt integrative rather than isolated interventions.

Plot expansion (Table 1) may necessitate proportional adjustments in labor deployment and input dosage. Farm management strategies—like synchronized planting and harvesting schedules—should reflect the collective effects observed. Moreover, the simultaneous analysis highlights synergistic or antagonistic relationships: for instance, the expanded land area may increase the effectiveness of fertilizer application but exacerbate pest pressures, requiring coordinated pest management. The policy implication was agricultural programs should design multi-pronged packages linking land optimization, workforce training modules, nutrient management protocols, and targeted pest-control strategies, ensuring that gains in one domain do not inadvertently reduce efficiency in another.

Table 4 presents the individual t-statistics and p-values for each regression coefficient, assessing the partial influence of variables X_1–X_6 on cocoa production.

Table 4. Partial Test (t-Test) of Regression Coefficients of Determinants of Cocoa Production Using Side Grafting

Variabel	B	Std. Error	Beta	t	Sig.
(Constant)	63.983	170.959	—	0.374	—
Land Area (X_1)	766.614	87.002	1.013	8.811	0.000[1]
Labor (X_2)	–31.466	23.884	–0.151	–1.317	0.201
Fertilizer (X_3)	0.029	0.257	0.015	0.113	0.911
Pesticides (X_4)	16.932	34.604	0.041	0.489	0.629
Plant Age (X_5)	–5.168	7.202	–0.057	–0.718	0.479
Farmer Skills (X_6)	2.208	10.276	0.013	0.215	0.832

[1] $p < 0.01$

The Tabel 4 showed that only Land Area (X_1) was individually significant; other factors do not show statistical significance. Partial t-tests reveal that only land area remains individually significant, while labor, fertilizer, pesticides, plant age, and farmer skills do not reach statistical significance. This suggests latent potential in non-significant factors that is not realized due to operational inefficiencies. Prasetyo & Wijayanti (2023) noted that smallholder farms often face labor scheduling constraints, while Rahmawati & Nugroho (2023) and Wijaya & Pramono (2024) reported inconsistent input application undermining agronomic returns. Smith & Jones (2025) highlighted that without systematic tree rejuvenation and formal extension services, variations in plant age and farmer expertise have minimal yield impact. To activate these latent effects, interventions must focus on: (1) labor optimization—such as community-based labor pools or mechanization incentives; (2) integrated nutrient–pest management training to synchronize fertilizer and pesticide schedules; and (3) structured tree pruning and grafting programs to rejuvenate aging trees.

The policy implication was holistic extension models combining labor management tools, integrated input calendars, and targeted tree management protocols are essential to unlock the potential contributions of these factors.

Table 5 presented each predictor's coefficient estimates, standard errors, t-values, p-values, and variance inflation factors (VIF) to diagnose multicollinearity and assess the individual contributions of X_1–X_3 to the regression model.

Table 5. Multicollinearity Test & Regression Coefficients of Determinants of Cocoa Production Using Side Grafting

Variable	B	Std. Error	Beta	t	p	VIF
(Constant)	6.108	1.360	—	4.491	.000	—
Pest Attack (X_1)	0.440	0.117	.426	3.750	.001	1.10
Maintenance (X_2)	0.441	0.120	.421	3.678	.001	1.12
Price (X_3)	0.401	0.130	.357	3.093	.004	1.08

Table 5 showed that regression equation: $Y = 6.108 + 0.440X_1 + 0.441X_2 + 0.401X_3$; VIF < 1.5 indicates no multicollinearity. Table 5's regression equation ($Y = 6.108 + 0.440X_1 + 0.441X_2 + 0.401X_3$) and VIF < 1.5 confirm both the linear relationship and absence of problematic multicollinearity among pest attack, maintenance, and price variables. The robust coefficients indicate that incremental changes in pest incidence, agronomic maintenance, and market price produce predictable shifts in farmers' land-conversion decisions. These findings suggest that policy levers can influence land use by manipulating these three dimensions. For example, integrated pest management (IPM) initiatives reduce β_1's effect by lowering baseline pest pressure. Advanced maintenance training—covering pruning, sanitation, and nutrient timing—enhances β_2's positive impact. Finally, price stabilization policies buffer β_3's influence, mitigating market volatility's impetus for land conversion. The policy implication showed that strategic investments in IPM extension, agronomic best-practice workshops, and price support mechanisms will collectively guide farmers toward sustainable land-use trajectories.

Table 6 presents the t-test outcomes for pest attack (X_1), maintenance (X_2), and price (X_3), each showing a positive, statistically significant contribution to farmers' decisions to convert cocoa land (all $p < .005$).

Table 6. The predictors land-conversion decisions of Cocoa Production Using Side Grafting

Variable	β	t	p
Pest Attack (X_1)	.440	3.750	.001
Maintenance (X_2)	.441	3.678	.001
Price (X_3)	.401	3.093	.004

Table 6 showed that all three predictors significantly influence land-conversion decisions with $R^2 = 0.608$. Table 6's partial results ($\beta_1 = 0.440$; $\beta_2 = 0.441$; $\beta_3 = 0.401$; all $p < .005$) demonstrate that pest attack, maintenance, and price each significantly predicts land-conversion decisions, jointly explaining 60.8% of the variance ($F(3,26)=16.007$; $p < .001$). Prihantini *et al.* (2024) identified pest incidence as a primary catalyst for cocoa-to-alternative crop transitions. Kouassi *et al.* (2023) underscored how improved maintenance practices bolster farmers' confidence in long-term cocoa cultivation. Fudjaja *et al.* (2024) confirmed that favorable price signals can delay or prevent land-use shifts by enhancing farm-gate returns.

Farmers facing severe pest pressures may find alternative crops more profitable, whereas robust maintenance regimens and stable prices can incentivize continued cocoa cultivation. These dynamics highlight the importance of synchronizing technical and market interventions. Governments and development agencies should implement targeted IPM campaigns, intensive maintenance demonstration plots, and guaranteed minimum price schemes to stabilize land-use decisions and foster sustainable cocoa landscapes.

Table 7 displays the variance inflation factors (VIF) alongside each predictor's coefficient estimate, standard error, t-statistic, and p-value for Pest Attack (X_1), Maintenance (X_2), and Price (X_3), confirming the absence of problematic multicollinearity and highlighting each variable's partial contribution to the model.

Table 7. The Variance Inflation Factors (VIF) of Cocoa Production Using Side Grafting

Variable	B	Std. Error	Beta	t	p	VIF
Constant	6.108	1.360	—	4.491	.000	—
Pest Attack (X_1)	0.440	0.117	.426	3.750	.001	1.10
Maintenance (X_2)	0.441	0.120	.421	3.678	.001	1.12
Price (X_3)	0.401	0.130	.357	3.093	.004	1.08

Table 7 showed the consistent coefficients and VIF < 1.5 confirm model stability, that the refined regression model ($Y = 6.108 + 0.440X_1 + 0.441X_2 + 0.401X_3$) maintains stability with VIF < 1.5 across variables, confirming the absence of multicollinearity. The intercept (a = 6.108) represents baseline conversion propensity when pest, maintenance, and price variables are zero. Each coefficient aligns with partial tests, reinforcing that (1) pest pressure, (2) maintenance practices, and (3) price fluctuations collectively shape land-use choices.

This stability suggests that combined interventions will not generate conflicting incentives. For instance, reducing pest pressures will uniformly reduce conversion propensity without unintended amplification of price effects. A coordinated policy portfolio—integrating IPM mandates, agronomic maintenance subsidies, and price stabilization funds—can deliver coherent signals to farmers, minimizing land depletion risks.

This subsection presents the individual t-test statistics for each predictor variable to assess their partial impact on farmers' land-conversion decisions.

Table 8. The variable that influence farmers' land conversion decisions

Variable	β	t	p
Pest Attack (X_1)	0.440	3.750	.001
Maintenance (X_2)	0.441	3.678	.001
Price (X_3)	0.401	3.093	.004

Table 8 showed that replicated tests reinforce the robustness of these predictors. Table 8 reconfirms the partial significance of pest attack ($t = 3.750$; $p = .001$), maintenance ($t = 3.678$; $p = .001$), and price ($t = 3.093$; $p = .004$), validating the consistency of these predictors in driving land conversion. The repeated t-tests amplify confidence in these variables' roles and magnitudes. Prihantini *et al*. (2024), Kouassi *et al*. (2023), and Fudjaja *et al*. (2024) consistently document these effects across varied regional contexts.

By reaffirming the predictive power of each factor, Table 8 underscores that multi-dimensional strategies are necessary: mitigating pest risks, enhancing maintenance regimes, and stabilizing market incentives.

Policy Implication: Policymakers should adopt integrated frameworks combining IPM, best-practice maintenance protocols, and safety-net pricing to ensure that land-use decisions align with long-term cocoa sector resilience.

IV. CONCLUSION

This study confirms that land area is the primary determinant of cocoa yield, while labor allocation, input usage, plant age, and farmer skills have a limited impact. Pest incidence, maintenance requirements, and price volatility collectively drive farmers' land conversion decisions. These findings summarize the contributions of production factors and land-use determinants observed through data analysis.

Develop land consolidation programs with targeted labor and input management training to leverage scale benefits. Enhance technical support via precision fertilization, micro-irrigation, and community-based pest management. Stabilize markets with minimum support prices and forward contracts to reduce land-conversion pressures.

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