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# Improving Sustainable Agriculture Adoption Among Smallholder Coffee Farmers in Indonesia: Does Entrepreneurial Orientation Play a Role?

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**Abstract.** The adoption of sustainable agriculture practices is essential for enhancing the environmental sustainability and long-term productivity of smallholder coffee farming systems. While previous studies have mainly focused on technical and institutional factors, the role of farmers' entrepreneurial orientation has received relatively little attention. This study examines how different dimensions of entrepreneurial orientation influence the adoption of sustainable agriculture practices among smallholder coffee farmers in Aceh Tengah, Indonesia. Data were collected from 156 coffee-farming households using a multi-stage random sampling approach. Sustainable agriculture adoption was measured as the total number of practices adopted, and the relationship was estimated using a Poisson regression model, with an ordered probit model employed as a robustness check. The results show that innovativeness ($\beta = 0.275$, *p* < 0.05) and proactiveness ($\beta = 0.271$, *p* < 0.05) are positively associated with the adoption of sustainable agriculture practices, whereas competitive aggressiveness ($\beta = -0.205$, *p* < 0.01) has a negative effect. In contrast, risk-taking and autonomy are not statistically significant. The robustness analysis using the ordered probit model produces consistent results, confirming the reliability of the main findings. These results suggest that encouraging farmers to be more innovative and proactive may be just as important as providing technical support. At the same time, stronger market incentives are needed to align competitiveness with sustainability goals better. The study also contributes to the entrepreneurial orientation literature by showing that its individual dimensions influence sustainable agriculture adoption in different ways, rather than having a uniform effect.

**Keyword:** coffee-farming; entrepreneurial orientation; long-term productivity; sustainable agriculture

## 1. Introduction

The sustainability of agricultural systems has become a central concern in global development, particularly in developing countries where smallholder farmers remain vulnerable to environmental degradation, market volatility, and institutional constraints (Amede et al., 2023; Khan et al., 2025). Sustainable agriculture is widely recognized as a pathway to improve productivity (Ejeta & Bai, 2025; Vishnoi & Goel, 2024), conserve natural resources (Rai et al., 2023), and strengthen rural livelihoods (Tang et al., 2013). However, adoption among smallholder farmers remains limited despite extensive policy promotion (Priya & Singh, 2024). In Indonesia, the transition toward sustainable agriculture is not only a technical issue but also a behavioral process influenced by farmers' perceptions, risk preferences, and strategic orientations toward innovation and opportunity (Suriansyah et al., 2024). Understanding these behavioral drivers is therefore essential, particularly in high-value commodity systems such as coffee production.

Indonesia is one of the world's leading coffee producers, and coffee farming plays an important role in rural livelihoods, export earnings, and landscape management (Andriani et al., 2025). Nevertheless, smallholder coffee farmers continue to face soil degradation, climate variability, declining productivity, and unstable market prices (Yuniarsih et al., 2024). Sustainable practices—including agroforestry, organic fertilization, soil and water conservation, integrated pest management, and certification systems—offer promising solutions to these challenges (Wijayanto et al., 2022). Yet adoption remains heterogeneous despite their well-established agronomic and

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environmental benefits (Chandel et al., 2024), suggesting that structural incentives alone, such as extension services and subsidies, cannot fully explain farmers' decisions.

A potentially important but underexplored determinant is entrepreneurial orientation (EO), a multidimensional construct encompassing innovativeness, risk-taking, proactiveness, competitive aggressiveness, and autonomy (Alshahrani et al., 2026; Fuller et al., 2026). Initially developed in entrepreneurship research, EO has increasingly been applied in agriculture to explain why some farmers actively pursue new opportunities, adopt innovations, and adapt more effectively to uncertainty (Andati et al., 2022). Because sustainable practices often require substantial investment, learning costs, and tolerance for delayed returns, EO may strongly influence farmers' willingness to adopt them (Abbas 2025; Osei & Zhuang, 2024).

The central problem addressed in this study is the persistent gap between the recognized importance of sustainable agriculture and its relatively slow adoption among coffee farmers. Existing policies generally assume that farmers will adopt sustainable practices once information, technology, or financial support becomes available (Barbosa, 2024; Mapanje et al., 2023). However, farmers differ considerably in how they perceive opportunities and constraints, even under similar institutional and ecological conditions (Rehman & Farooq, 2023). Farmers with stronger entrepreneurial orientations may regard sustainable practices as strategic investments that enhance long-term resilience and competitiveness, whereas others may perceive them as costly and risky. Ignoring this heterogeneity may reduce the effectiveness of policy interventions.

Previous studies have identified education, farm size, extension access, credit, social capital, and market access as important determinants of sustainable agriculture adoption (Mgomezulu et al., 2023; Oumer et al., 2025). Although these studies provide valuable insights, they often portray farmers as passive recipients of external incentives rather than strategic decision-makers. More recent research has incorporated behavioral perspectives, emphasizing the roles of attitudes, perceptions, and preferences (Pham et al., 2022; Ramborun et al., 2020). Within this literature, EO has been linked to the adoption of crop diversification, climate-smart agriculture, conservation practices, and technological innovations, particularly in developing countries.

Evidence from Asia and Africa further indicates that farmers with stronger innovativeness and risk-taking tendencies are more likely to adopt adaptive and sustainable practices under climate and market uncertainty (Abbas et al., 2025; Andati et al., 2022). Entrepreneurially oriented farmers tend to experiment with new production methods, respond proactively to changing conditions, and seek opportunities to improve farm performance (Dias et al., 2021; Umar et al., 2020). However, most existing studies focus on staple crops or general farming systems (Andati et al., 2022; Dias et al., 2021; Oumer et al., 2025), while research on export-oriented perennial crops such as coffee remains limited. Moreover, many studies measure EO using only selected dimensions, often excluding competitive aggressiveness and autonomy, despite their relevance for market-oriented farming systems.

Coffee farming provides a particularly relevant context because production involves long investment cycles, quality-sensitive markets, and increasing sustainability requirements. Practices such as agroforestry and organic fertilization often involve short-term costs but generate long-term benefits through improved soil health, climate resilience, and potential price premiums. Farmers with stronger entrepreneurial orientation may therefore be better equipped to recognize and exploit these intertemporal trade-offs.

This study addresses these gaps by examining the relationship between

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entrepreneurial orientation and sustainable agriculture adoption among smallholder coffee farmers in Aceh, Indonesia. Aceh provides an appropriate empirical setting because coffee production is dominated by smallholders operating within diverse institutional arrangements, including farmer organizations, certification schemes, extension services, and traditional community networks. At the same time, farmers participate in quality-sensitive export markets while facing climate variability, long production cycles, and increasing sustainability standards. These conditions create substantial variation in the opportunities and constraints surrounding sustainable agriculture adoption, making entrepreneurial orientation particularly important in explaining farmers' decisions.

Sustainable agriculture adoption is conceptualized as a composite index representing multiple practices commonly promoted in coffee production, including agroforestry integration, organic fertilizer use, soil and water conservation, integrated pest management, certification participation, recommended input use, and simple irrigation technologies (Hasibuan et al., 2022; Yuniarsih et al., 2024). This multidimensional approach captures variation in adoption intensity more effectively than binary measures (Sukayat et al., 2023).

This study contributes to the literature in three ways. First, it extends entrepreneurial orientation theory by demonstrating how its multidimensional components influence sustainable agriculture adoption within heterogeneous smallholder coffee systems, thereby strengthening the external validity of EO beyond conventional business contexts. Second, it advances the measurement of sustainable agriculture by employing an additive adoption index that captures differences in adoption intensity rather than simple adoption status (Sukayat et al., 2023). Third, it provides policy-relevant evidence by showing that strengthening entrepreneurial capabilities may be as important as providing technical and institutional support for accelerating sustainability transitions among smallholder coffee farmers.

## 2. Materials and Methods

### 2.1. Study Area and Sampling Procedure

This study was conducted in Aceh Tengah Regency, Aceh Province, Indonesia, one of the country's major coffee-producing regions and the center of Arabica Gayo coffee production. The study area was purposively selected because of its strategic contribution to national coffee production, the dominance of smallholder coffee farmers, and the increasing importance of sustainable agricultural practices in the region (Salasamuharram et al., 2024).

A multi-stage sampling technique was employed. First, Aceh Tengah Regency was purposively selected. Second, four villages were chosen, comprising two transmigrant villages and two indigenous Gayo villages, to capture socio-cultural differences in farming experience, production systems, and entrepreneurial characteristics. Third, coffee farmer lists obtained from village offices and agricultural extension services were used as the sampling frame. Forty farmers were randomly selected from each village, yielding 160 respondents. After data cleaning, four observations with substantial missing information were excluded, resulting in a final sample of 156 coffee farmers.

Primary data were collected through face-to-face interviews using a structured questionnaire to ensure accurate responses and minimize misinterpretation, particularly given respondents' varying educational backgrounds. The questionnaire, developed from previous studies on Entrepreneurial Orientation (EO), sustainable agriculture, and agricultural technology adoption, measured entrepreneurial characteristics, sustainable practice adoption, socio-economic conditions, and farm characteristics. Established scales were adapted to the local coffee farming context to ensure content validity. Focus Group Discussions (FGDs)

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with extension officers, local leaders, farmer group representatives, and selected farmers complemented the survey by exploring perceptions of sustainability, adoption challenges, and entrepreneurial behavior. Data collection was conducted by trained bilingual enumerators who received standardized training on research objectives, interview procedures, questionnaire administration, and ethical considerations to ensure consistency and minimize interviewer bias.

### 2.2. Measurement of key variable

Entrepreneurial orientation (EO) is the main explanatory variable in this study. It is conceptualized as a multidimensional behavioral construct reflecting farmers' strategic attitudes toward innovation, opportunity recognition, and decision-making under uncertainty. EO is measured using five core dimensions: innovativeness, proactiveness, risk-taking, competitive aggressiveness, and autonomy (Al-Mamary & Alshallaqi, 2022; Okręglicka et al., 2023). Each dimension is captured through multiple reflective items adapted to the context of smallholder coffee farming, as presented in Table 1. All EO items are assessed using a five-point Likert scale ranging from 1 to 5, with higher values indicating a stronger entrepreneurial orientation.

For empirical analysis, EO dimensions are operationalized using a mean-score approach (Feng & Hancock, 2024). Specifically, the value of each EO dimension is calculated as the arithmetic mean of all items associated with that dimension, as reported in Table 1. This approach ensures that each item contributes equally to the construct and avoids disproportionate weighting driven by the number of indicators. Reliability analysis confirms satisfactory internal consistency across all EO dimensions, supporting the aggregation of items into composite measures. Using mean scores also preserves the original scale of measurement, allowing for straightforward interpretation of estimated coefficients in subsequent econometric models. Rather than collapsing EO into a single index, the analysis retains each EO dimension separately to capture potential heterogeneity in how different entrepreneurial traits influence sustainable agriculture adoption.

The dependent variable is the adoption of sustainable agriculture practices (SAP), measured as the sum of seven binary indicators, producing an index ranging from 0 to 7:

$$SAP_i = \sum_{j=1}^{7} SAP_{ij}$$

where $SAP_{ij} = 1$ when farmer $i$ satisfies the adoption criterion for practice $j$, and $SAP_{ij} = 0$ otherwise.

Adoption is assessed based on practices implemented during the 12 months preceding the survey, except for long-term investments (agroforestry, certified planting materials, and irrigation systems), which are evaluated based on their current presence and use. The seven practices comprise: (1) agroforestry integration through actively managed shade trees; (2) organic fertilizer application at least once during the previous year; (3) implementation of soil and water conservation measures, such as terracing, contour planting, mulching, vegetative strips, or drainage channels; (4) integrated pest management combining pest monitoring with at least one biological, mechanical, cultural, or sanitation-based control method, excluding sole reliance on chemical pesticides; (5) use of certified planting materials obtained from officially recognized suppliers; (6) fertilizer application broadly consistent with extension recommendations, soil-test results, or official production guidelines; and (7) use of a functional irrigation system during dry periods.

Information was collected through structured farmer interviews and, where feasible, verified by enumerator observations or supporting documents, including seed labels, extension recommendations, and farm records. Each practice received equal weight

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because the index was designed to measure the breadth of sustainable agriculture adoption rather than differences in the cost, complexity, or environmental contribution of individual practices.

### 2.3. Validity and reliability test

Because entrepreneurial orientation (EO) represents a latent behavioral construct that cannot be directly observed, it is essential to assess the validity and reliability of its measurement before conducting empirical analysis. EO is captured through farmers' self-reported responses to multiple survey items, which may be subject to measurement error if the indicators do not consistently reflect the underlying constructs. Therefore, establishing validity and reliability ensures that the EO dimensions are measured accurately and that subsequent empirical results are robust and interpretable.

**Table 1.** Entrepreneur orientation.

| EO Dimension | Indicators | Statement | Scale |
|---|---|---|---|
| Innovativeness | EO_IN1 | I always try new methods in coffee cultivation to improve yields. | 1–5 |
| | EO_IN2 | I am interested in trying new coffee varieties that have better market potential. | 1–5 |
| | EO_IN3 | I actively seek new technologies to improve the quality of my coffee. | 1–5 |
| | EO_IN4 | I create innovations in post-harvest processes (drying, fermentation, packaging). | 1–5 |
| Proactiveness | EO_PR1 | I seek market information before the harvest season begins. | 1–5 |
| | EO_PR2 | I anticipate changes in consumer demand and adjust my production accordingly. | 1–5 |
| | EO_PR3 | I build networks with buyers before the harvest season. | 1–5 |
| | EO_PR4 | I actively participate in coffee training or exhibitions to expand business opportunities. | 1–5 |
| Risk-taking | EO_RT1 | I am willing to try new methods even though there is a risk of failure. | 1–5 |
| | EO_RT2 | I am willing to invest capital in new technologies to increase productivity. | 1–5 |
| | EO_RT3 | I am willing to take the risk of fluctuating selling prices in order to try new markets. | 1–5 |
| Competitive Aggressiveness | EO_CA1 | I strive to offer better coffee quality than other farmers in my area. | 1–5 |
| | EO_CA2 | I quickly adjust price or quality when new competitors enter the market. | 1–5 |
| | EO_CA3 | I implement specific strategies to retain loyal buyers. | 1–5 |
| Autonomy | EO_AU1 | I make decisions about my coffee farming business independently. | 1–5 |
| | EO_AU2 | I set the long-term goals of my coffee business on my own. | 1–5 |
| | EO_AU3 | I manage planting, harvesting, and marketing schedules without waiting for directions from others. | 1–5 |

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Validity and reliability of the EO measures were evaluated using standard psychometric criteria. Convergent validity was assessed by examining indicator loadings and the average variance extracted (AVE), ensuring that each construct adequately explains the variance of its indicators. Composite reliability (CR) and Cronbach's alpha (CA) were used to evaluate internal consistency, with values exceeding conventional threshold levels indicating satisfactory reliability (Purwanti et al., 2022). Discriminant validity was examined using the square root of AVE, confirming that each EO dimension is empirically distinct from the others.

Because both the dependent and independent variables were collected through self-reported interviews, common method bias (CMB) was assessed using Harman's single-factor test. The first unrotated factor accounted for less than 50% of the total variance, indicating that common method bias is unlikely to pose a serious threat to the validity of the results.

### 2.4. Estimation Strategy

In estimating the impact of entrepreneurial orientation (EO) on sustainable agriculture practice (SAP) adoption, this study employs a Poisson regression model as the main specification because the dependent variable, SAP total**,** is a non-negative count measure (0–7) representing the number of sustainable practices adopted by each farmer.

Before estimating the model, the equidispersion assumption underlying the Poisson specification was evaluated using the Pearson goodness-of-fit statistic. The Pearson chi-square statistic was 162.34 with 156 degrees of freedom, yielding a dispersion statistic of 1.04 (Pearson $\chi^2$/df). Following Cameron & Trivedi (2013), a dispersion statistic close to one indicates that the equidispersion assumption is satisfied, whereas substantially larger values indicate overdispersion. Because the estimated dispersion statistic was 1.04, which is close to one, there was no evidence of substantial overdispersion. Therefore, the Poisson regression model was considered appropriate for the main analysis.

The Poisson model is appropriate for modeling count outcomes and links the expected number of adopted practices to EO dimensions and control variables through a log-linear functional form. Formally, let $SAP_i$ denote the total SAP adoption score for farmer iii. The conditional mean is specified as $E(SAP_i|X_i) = \mu_i$ , where $\mu_i = exp(X_i'\beta)$. Accordingly, the estimating equation can be written as follows:

$$ln(\mu_i) = X_i'\beta$$

where $X_i$ includes the five EO dimensions (innovativeness, proactiveness, risk-taking, competitive aggressiveness, and autonomy) and a set of demographic and farm-level controls (e.g., age, education, gender, farming experience, ethnicity, household size, land area, and productive coffee plants). Coefficients are interpreted in terms of proportional changes in the expected SAP count, holding other factors constant.

As a robustness check, the study also estimates an ordered probit model using an ordinal version of SAP adoption, $SAP_i^{level}$, which classifies farmers into ordered categories of adoption intensity (e.g., low, medium, and high). The ordered probit framework assumes an unobserved latent propensity to adopt sustainable practices, $SAP_i^*$, defined as follows:

$$SAP_i^{level} = X_i'\delta + \varepsilon_i$$

where $\varepsilon_i \sim$ N(0,1) . The observed adoption level is generated by threshold parameters such that:

$$SAP_i^{level} = \begin{cases} 1 \; if \; SAP_i^* < c_1 \\ 2 \; if \; c_1 < SAP_i^* < c_2 \\ 3 \; if \; SAP_i^* > c_2 \end{cases}$$

with $c_1$ and $c_2$ estimated from the data. This robustness specification tests whether the

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direction and statistical significance of EO effects remain consistent when SAP adoption is modeled as an ordered outcome rather than a count, thereby strengthening the credibility of the empirical findings.

Although entrepreneurial orientation may be associated with sustainable agriculture adoption through reciprocal behavioral processes, the present study relies on cross-sectional observational data and does not claim causal inference. Suitable external instrumental variables were not available; therefore, the estimated coefficients should be interpreted as conditional associations rather than causal effects. Future studies employing panel data, instrumental variable approaches, or experimental designs would provide stronger evidence regarding the causal relationship between entrepreneurial orientation and sustainable agriculture adoption.

Moreover, the Durbin–Wu–Hausman endogeneity test produced a $\chi^2$ statistic of 1.87 ($p = 0.171$), indicating that the null hypothesis of exogeneity could not be rejected and providing no statistical evidence that entrepreneurial orientation is endogenous in the estimated model. Nevertheless, the results should be interpreted as robust conditional associations rather than definitive causal effects because unobserved factors, including managerial ability, environmental attitudes, and social networks, as well as measurement error arising from self-reported responses, may still influence the estimated coefficients.

## 3. Results and Discussion

### 3.1. Descriptive Statistics

Table 2 presents the descriptive characteristics of the sampled coffee farmers. On average, farmers adopted 2.58 of the seven sustainable agriculture practices, indicating a low to moderate level of adoption and considerable scope for expanding sustainable coffee production. The average farmer is 45.21 years old, suggesting that middle-aged producers with substantial productive capacity dominate coffee farming. Farmers have completed an average of 8.37 years of formal education, equivalent to junior secondary school, reflecting moderate human capital that may influence their ability to process information and adopt sustainable innovations.

Approximately 29.5% of respondents are male, indicating substantial female participation in coffee farming and underscoring the importance of gender considerations in promoting sustainable agriculture. Farmers have an average of 9.77 years of coffee farming experience, suggesting considerable practical knowledge that may shape innovation and management decisions. Nearly 48.7% of respondents are transmigrants, reflecting a balanced composition between local (Gayo) and transmigrant communities, which may influence farming practices, social networks, and institutional access. Average household size is 3.39 members, indicating relatively small households that may face labor constraints in implementing labor-intensive sustainable practices. The average coffee farm covers 1.17 hectares with approximately 1,460 productive coffee plants, confirming that the sample consists predominantly of smallholder farmers operating at a moderate production scale.

### 3.2. The adoption of sustainable agriculture practices

Adoption rates (%) of individual sustainable agriculture practices among smallholder coffee farmers in Aceh, Indonesia (n = 156). The figure reports the proportion of farmers adopting each of the seven sustainable agriculture practices included in the Sustainable Agriculture Practices (SAP) index: agroforestry integration, organic fertilizer use, soil and water conservation, integrated pest management, certified planting-material use, recommended fertilizer application, and simple irrigation systems.

Figure 1 presents the adoption rates of the seven sustainable agriculture practices

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included in the SAP index. Considerable variation is observed across practices, indicating that farmers adopt sustainable practices selectively rather than as a comprehensive package. This heterogeneity suggests that differences influence adoption decisions in perceived benefits, implementation costs, technical complexity, and compatibility with existing farming systems.

**Table 2.** Descriptive Statistics

| Variable Name | Measurement | Mean | Std. Dev. |
|---|---|---|---|
| SAP Total | Total adoption score of sustainable agriculture practices (range: 0–7) | 2.577 | 1.828 |
| Age | Age of the farmer (years) | 45.212 | 9.613 |
| Education | Years of formal education completed by the farmer | 8.365 | 4.863 |
| Gender | Gender dummy: 1 = male, 0 = female | 0.295 | 0.457 |
| Farming Experience | Years of experience in coffee farming | 9.769 | 2.470 |
| Ethnicity | Ethnicity dummy: 1 =transmigrant (Gayo), 0 = local | 0.487 | 0.501 |
| Household Size | Number of household members | 3.385 | 1.247 |
| Land Area | Total area under coffee cultivation (Ha) | 1.165 | 0.500 |
| Productive Coffee | Number of productive coffee plants | 1459.615 | 634.267 |
| Number of Obs. | 156 | | |

Simple irrigation systems exhibit the highest adoption rate (85.9%), followed by soil and water conservation practices (76.3%), organic fertilizer use (72.4%), certified planting-material use (70.5%), and integrated pest management (64.7%). The relatively high adoption of these practices suggests that farmers are more likely to implement technologies that provide immediate production benefits, improve resource-use efficiency, or have been widely promoted through extension and development programs.

In contrast, agroforestry integration (26.9%) and recommended fertilizer application (26.3%) show substantially lower adoption rates. These practices generally require greater technical knowledge, longer planning horizons, or higher initial investments, which may discourage adoption among resource-constrained smallholder farmers. Overall, the observed variation highlights that sustainable agriculture adoption is a gradual and multidimensional process, with farmers adopting individual practices incrementally rather than simultaneously.

### 3.3. Validity and Reliability

The results of the confirmatory factor analysis are reported in Table 3, which demonstrates that the measurement model for entrepreneurial orientation (EO) exhibits strong psychometric properties. All indicators show satisfactory factor loadings, generally exceeding the recommended threshold of 0.70, indicating that the observed items adequately capture their respective latent constructs. In addition, Cronbach's alpha (CA) and composite reliability (CR) values for all EO dimensions are well above the minimum acceptable level of 0.70, confirming a high degree of internal consistency and reliability (Putritamara et al., 2025).

Convergent validity is further supported by the average variance extracted (AVE) values presented in Table 3. All AVE values exceed the commonly accepted threshold of 0.50, suggesting that each EO construct explains more than half of the variance in its

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associated indicators. Notably, the proactiveness and risk-taking dimensions display particularly high AVE values, indicating precise and consistent measurement of these entrepreneurial traits (Purwanti et al., 2023).

Discriminant validity was assessed using the Fornell–Larcker criterion, as reported in Table 4. The square root of the AVE for each construct, shown on the diagonal, is greater than all corresponding inter-construct correlations in the same row and column. This indicates that each dimension of entrepreneurial orientation shares more variance with its own indicators than with the other constructs. Although several dimensions show moderate correlations, particularly proactiveness and risk-taking, these relationships remain below the corresponding diagonal values. Therefore, the Fornell–Larcker criterion is satisfied for all five constructs. Taken together with the reliability and convergent validity results reported in Table 3, these findings confirm that the EO measurement model demonstrates adequate validity and reliability for the subsequent empirical analysis.

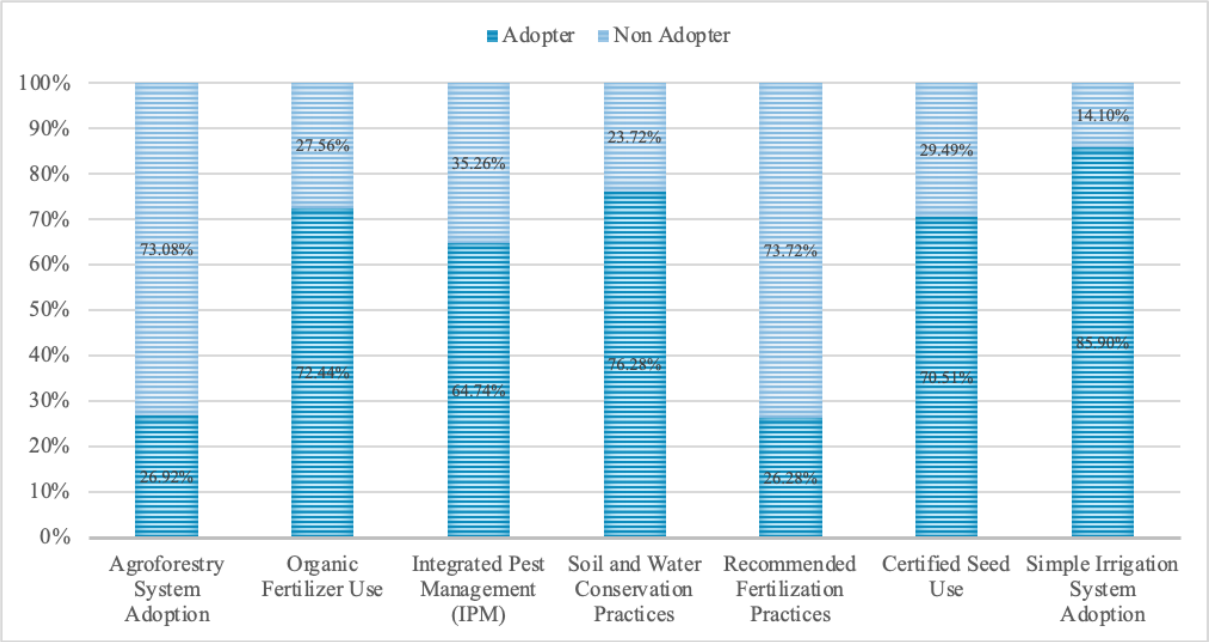


**Figure 1.** Sustainable Agriculture Practices

### 3.4. Empirical results

Table 5 reports the relationship between entrepreneurial orientation (EO) and sustainable agriculture practice (SAP) adoption among smallholder coffee farmers. The main analysis uses a Poisson regression because the dependent variable is a count index of adopted practices. At the same time, an ordered probit model serves as a robustness check based on adoption intensity (Ma & Wang, 2020). Consistent coefficient signs and significance across both models, together with the absence of substantial overdispersion, confirm the suitability and robustness of the Poisson specification.

Innovativeness has a positive and significant effect on SAP adoption, indicating that innovative farmers adopt a broader range of practices, including agroforestry, integrated pest management, soil conservation, and organic fertilization. This finding supports innovation diffusion theory (Jiang et al., 2025) and previous evidence from developing countries (Mondal et al., 2024; Mukhtar et al., 2025). Given increasing climate variability and sustainability requirements in Indonesian coffee markets,

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strengthening farmers' innovative capacity through demonstration plots, farmer field schools, participatory learning, and innovation-oriented extension services may be more effective than relying solely on financial incentives.

Proactiveness also positively influences SAP adoption, suggesting that farmers who anticipate future environmental and market changes are more likely to invest in sustainable practices. This result is consistent with previous studies (Frare & Beuren, 2022; Tyler et al., 2024). In Indonesia's coffee sector, proactive farmers appear to view sustainability as a long-term competitive strategy rather than merely a regulatory obligation, highlighting the need for policies that combine technology dissemination with strategic planning and climate adaptation.

**Table 3.** Analysis of confirmatory factors

| Construct | Indicator | Loading | CA | CR | AVE |
|---|---|---|---|---|---|
| Innovativeness | EO_IN1 | 0.768 | 0.88 | 0.864 | 0.696 |
| | EO_IN2 | 0.782 | | | |
| | EO_IN3 | 0.751 | | | |
| | EO_IN4 | 0.834 | | | |
| Proactiveness | EO_PR1 | 0.922 | 0.966 | 0.952 | 0.794 |
| | EO_PR2 | 0.919 | | | |
| | EO_PR3 | 0.917 | | | |
| | EO_PR4 | 0.896 | | | |
| Risk-taking | EO_RT1 | 0.835 | 0.914 | 0.902 | 0.776 |
| | EO_RT2 | 0.879 | | | |
| | EO_RT3 | 0.86 | | | |
| Competitive aggressiveness | EO_CA1 | 0.725 | 0.917 | 0.783 | 0.612 |
| | EO_CA2 | 0.707 | | | |
| | EO_CA3 | 0.768 | | | |
| Autonomy | EO_AU1 | 0.755 | 0.873 | 0.814 | 0.658 |
| | EO_AU2 | 0.789 | | | |
| | EO_AU3 | 0.757 | | | |
| Number of obs. | 156 | | | | |

**Table 4.** Discriminant validity

| Construct | Innovativeness | Proactiveness | Risk-taking | Competitive aggressiveness | Autonomy |
|---|---|---|---|---|---|
| Innovativeness | 0.834 | 0.721 | 0.653 | 0.341 | 0.402 |
| Proactiveness | 0.721 | 0.891 | 0.781 | 0.518 | 0.356 |
| Risk-taking | 0.653 | 0.781 | 0.881 | 0.495 | 0.389 |
| Competitive aggressiveness | 0.341 | 0.518 | 0.495 | 0.782 | 0.281 |
| Autonomy | 0.402 | 0.356 | 0.389 | 0.281 | 0.811 |
| Number of obs. | 156 | | | | |

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Risk-taking, however, is not statistically significant, implying that adoption decisions are not primarily driven by individual risk preferences. This may reflect the inherently risky nature of coffee production, where sustainable practices are perceived as risk-reducing rather than risk-increasing. Furthermore, widespread dissemination through extension programs, farmer organizations, and certification initiatives has reduced perceived technological uncertainty, while liquidity constraints often outweigh farmers' willingness to take risks. These findings suggest that institutional support and financial access are more important than encouraging greater entrepreneurial risk-taking.

Competitive aggressiveness shows a negative and significant relationship with SAP adoption. Unlike conventional entrepreneurship studies linking competitive aggressiveness to better firm performance (Fischer, 2023), aggressive competition among Indonesian coffee farmers appears to encourage short-term productivity and income maximization at the expense of long-term sustainability. Because sustainability premiums remain limited while local markets continue rewarding production volume, farmers have fewer incentives to invest in practices with delayed returns. Stronger certification premiums, sustainability-based procurement, and value-chain partnerships are therefore needed to align market competition with sustainable production.

Autonomy is not significantly associated with SAP adoption, indicating that independent decision-making alone does not increase adoption. Instead, sustainable farming depends heavily on collective learning, extension services, farmer organizations, cooperatives, and certification programs that facilitate knowledge exchange and market access. This finding supports the argument that sustainability is embedded within collaborative institutional environments rather than individual entrepreneurial behaviour (Hazard et al., 2022).

These results offer several theoretical implications. First, EO is clearly multidimensional, with innovativeness and proactiveness driving sustainability adoption. In contrast, risk-taking and autonomy have no independent effects under the institutional and market conditions faced by Indonesian coffee farmers. Second, the negative effect of competitive aggressiveness demonstrates that EO should not be viewed as uniformly beneficial for sustainability; its influence depends on institutional environments, market incentives, and production systems. Finally, the findings extend EO theory to smallholder agriculture by showing how entrepreneurial traits interact with local institutions and market structures. Future studies should therefore examine each EO dimension separately rather than relying on a single composite measure.

Among the control variables, gender significantly influences SAP adoption, with male farmers being less likely to adopt sustainable practices, consistent with evidence that women generally demonstrate stronger environmental concern (Kassinis et al., 2016). Education positively affects adoption by improving farmers' ability to process information and evaluate long-term benefits (Adnan et al., 2018; Davis et al., 2010; Rahman, Nugroho, et al., 2025; Rahman, Toiba, et al., 2025). Ethnicity is also significant, as transmigrant farmers are less likely to adopt SAP than indigenous farmers, highlighting the importance of local knowledge, social capital, and tenure security (Nugroho et al., 2022; Yusriadi, 2025). Larger landholdings are positively associated with higher adoption intensity, consistent with previous studies showing that larger farms possess greater financial flexibility for experimentation (Shaleh et al., 2024; Toiba et al., 2024). In contrast, age, farming experience, household size, and the number of productive coffee plants are not significant, suggesting that SAP adoption depends more on behavioural orientation, human capital, social capital, and institutional support than on demographic characteristics

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or accumulated farming experience alone (Frare & Beuren, 2022; Tyler et al., 2024). These findings indicate that sustainability policies should prioritize knowledge enhancement, extension services, institutional support, and targeted assistance for women, transmigrant farmers, and resource-constrained households.

**Table 5.** Empirical Estimation

| Variables | Poisson Regression | | Ordered Probit | |
|---|---|---|---|---|
| | Coef. | (Std. Err.) | Coef. | (Std. Err.) |
| Innovativeness | 0.275 | (0.135)** | 5.071 | (1.230)*** |
| Proactiveness | 0.271 | (0.129)** | 1.966 | (0.755)*** |
| Risk-taking | -0.048 | (0.114) | -0.409 | (0.488) |
| Competitive Aggressiveness | -0.205 | (0.079)*** | -2.255 | (0.847)*** |
| Autonomy | 0.016 | (0.120) | -0.049 | (0.626 |
| Gender | -0.245 | (0.152)* | -2.990 | (1.348)*** |
| Age | 0.003 | (0.007) | -0.001 | (0.050) |
| Education | 0.029 | (0.017)* | 0.151 | (0.092)* |
| Farming Experience | -0.006 | (0.021) | 0.184 | (0.131) |
| Ethnicity | -0.323 | (0.136)** | -1.538 | (0.712)** |
| Household Size | 0.005 | (0.044) | -0.309 | (0.206) |
| Land Area | 0.032 | (0.127) | 1.750 | (0.756)** |
| Productive Coffee | 0.000 | (0.000) | 0.000 | (0.001) |
| Cons | -0.450 | (0.710) | | |
| Cut1 | | | 19.901 | (5.388) |
| Cut2 | | | 24.212 | (6.029) |
| Log likelihood | -222.365 | | -22.801 | |
| LR chi2 | 154.770 | | 227.350 | |
| Prob > chi2 | 0.000 | | 0.000 | |
| Pseudo R2 | 0.258 | | 0.833 | |
| Number of obs. | 156 | | | |

Note: *p < 0.10; ** p < 0.05; *** p < 0.01

## 4. Limitations and Future Directions

Despite providing new evidence on the role of entrepreneurial orientation in shaping sustainable agriculture adoption among smallholder coffee farmers, this study has several limitations. First, the analysis is based on cross-sectional data, capturing entrepreneurial orientation and adoption behavior at a single point in time. Therefore, the estimated relationships should be interpreted as associations rather than causal effects. Future studies should employ longitudinal or panel data to examine changes in entrepreneurial orientation over time and their influence on sustained adoption. Experimental and quasi-experimental designs, such as randomized interventions or field experiments, would further strengthen causal inference.

Second, this study focuses on smallholder coffee farmers in Aceh Tengah, Indonesia, whose distinctive socio-cultural, institutional, and agroecological characteristics may limit the generalizability of the findings. Since the influence of entrepreneurial orientation may differ across institutional environments, market structures, commodities, and farming systems, future

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research should conduct comparative studies across regions and countries to assess the consistency of these relationships.

Finally, entrepreneurial orientation was measured using self-reported data, which may be subject to response bias despite satisfactory validity and reliability. Future research should combine behavioral measures with survey data to provide more rigorous evidence. In addition, studies should examine potential mediation and moderation mechanisms, including access to extension services, social capital, digital technology adoption, and market participation, while incorporating spatial and environmental factors such as climate conditions, land suitability, topography, and market accessibility. These approaches would strengthen both the internal and external validity of the findings and provide more robust guidance for agricultural policy and sustainable farming practices.

## 5. Conclusion

This study examined the relationship between entrepreneurial orientation and sustainable agriculture adoption among smallholder coffee farmers in Aceh Tengah, Indonesia. The findings show that entrepreneurial orientation is multidimensional, with innovativeness and proactiveness positively influencing sustainable agriculture adoption, while competitive aggressiveness may discourage sustainability-oriented investments under certain market conditions. These results highlight the importance of behavioral characteristics alongside conventional socioeconomic factors in promoting agricultural sustainability.

This study contributes to the literature in three ways. First, it extends Entrepreneurial Orientation theory by showing that individual EO dimensions influence sustainable agriculture differently and should be examined separately rather than as a single composite construct. Second, it provides empirical evidence from a perennial cash crop system in a developing-country context, where such evidence remains limited. Third, by measuring sustainable agriculture adoption as the cumulative implementation of multiple practices, it offers a more comprehensive assessment than conventional binary adoption measures.

The findings also have important policy implications. Promoting sustainable agriculture should go beyond technical assistance and financial incentives by strengthening farmers' entrepreneurial capabilities, particularly innovativeness and proactiveness. Extension services should foster experimentation, continuous learning, and long-term planning, while market policies should provide stronger incentives for sustainable production through certification and sustainability-based rewards. Overall, integrating entrepreneurial capacity building into sustainable agriculture policies can accelerate sustainability transitions while improving the resilience and competitiveness of smallholder coffee farming systems.

### Declaration of Generative AI and AI-Assisted Technologies in the Writing Process

During the preparation of this manuscript, the authors used ChatGPT (OpenAI) for language editing and readability improvement. All scientific content, analyses, interpretations, and conclusions are solely the responsibility of the authors, who reviewed and approved the final manuscript.

### Authorship Contribution Statement

Mangku Purnomo: Conceptualization, Methodology, Supervision, Validation, Writing – review & editing. Tri Wahyu Nugroho: Investigation, Data curation, Formal analysis, Writing – original draft, Writing – review & editing. Suhartini: Validation, Literature review, Writing – review & editing. Budi Setiawan: Formal analysis, Validation, Writing – review & editing. Setiyo Yuli Handono: Data curation, Validation, Manuscript editing, Writing – review & editing.

### Declaration of Competing Interest

The authors declare that they have no competing interests relevant to this article.

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