

Analysis of Yield Volatility and Identification of Production Risk Sources of Arabica Coffee (*Coffea Arabica* L.) in Karo Regency

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ABSTRACT

The sustainability of Arabica coffee farming in Karo Regency is confronted with yield volatility arising from technical, biological, and environmental factors. This study aims to identify sources of production risk using a quantitative Z-Score approach and to analyze the level of relative risk using the Coefficient of Variation (CV) and standard deviation. This mixed-methods study was conducted in Simpang Empat District and involved 200 coffee farmers (100 PT Olam partner farmers and 100 traditional non-partner farmers). The results show that, at the aggregate level, the relative risk of Arabica coffee farming in Karo Regency is low and stable, with an average CV of 8.85% and an operational loss probability of only 14.12%. Based on the Z-Score analysis of 25 risk indicators, a deconstruction of the conventional risk paradigm was identified, whereby the main risk sources categorized as occurring very frequently were dominated by downstream market requirements. These included strict requirements for packaged products, with an occurrence probability of 85%, and the requirement for products to have trademarks, also with an occurrence probability of 85%. In contrast, upstream risks such as declines in selling prices (11%) and pest and disease attacks (11%–12%) had the lowest probabilities and were therefore categorized as very rare. The study concludes that although farming activities generally remain within a safe zone, farmers need to strengthen their adaptive capacity to modern market regulations in the downstream sector.

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INTRODUCTION

Indonesia is an agrarian country in which agriculture serves as a primary sector and a source of foreign exchange. Amid international trade competition, coffee was recorded as the agricultural commodity with the highest export value in 2024. From an economic perspective, coffee cultivation provides opportunities for income diversification and significant improvements in rural livelihoods. North Sumatra is one of Indonesia's major coffee-producing regions, particularly for Arabica coffee, which thrives in highland areas. Karo Regency ranks among the top five coffee-producing areas in North Sumatra, making it an important contributor to the province's coffee production.

However, the sustainability of Arabica coffee farming in Karo Regency remains exposed to yield volatility resulting from technical, biological, and environmental factors. According to production economics, farming risks can be classified into production, market/price, financial, and human resource risks. Production risk includes declines in productivity, low quality, and crop failure, all of which influence farmers' decisions regarding input allocation. Therefore, this study aims to quantitatively analyze the level of relative production risk and identify the probability of occurrence of various upstream and downstream risk sources in Karo Regency. By understanding the distribution of yield data, this study is expected to provide a preventive foundation for stabilizing the income of smallholder farmers.

METHODOLOGY

This study employed a mixed-methods approach integrating quantitative and qualitative approaches. The research location was purposively selected in Simpang Empat District, Karo Regency, North Sumatra Province, considering that the area is one of the major centers of Arabica coffee production and has diverse farming-related problems. The study was conducted over 12 months, from January to December 2026.

The population in this study consisted of Arabica coffee farmers in Karo Regency. Purposive sampling was used to select the focus villages, namely Kuta Tengah Village and Lingga Village in Simpang Empat District. A total of 200 coffee farmers participated as respondents, proportionally consisting of 100 farmers from the PT Olam assisted group in Kuta Tengah Village, 50 non-assisted farmers in Kuta Tengah Village, and 50 traditional non-assisted farmers in Lingga Village.

Primary data were collected through in-depth interviews, field observations, and structured questionnaires measured using a Likert scale. To identify sources of production risk, the data were analyzed using the Z-Score transformation method with the following formula:

$$Z = \frac{Xi - X}{S}$$

Where Z is the Z-Score value, Xi is the normal risk threshold, X is the mean value of the risk event, and S is the standard deviation. Furthermore, the Coefficient of Variation (CV) was used to analyze the level of production risk, using the following formula:

$$CV = (\text{Standar Deviasi} / \text{Rata - rata}) \times 100\%$$

Farming activities are categorized as having low and stable risk when the CV value is < 0.50 or less than 50%. Quantitative data processing was performed using Microsoft Excel and SPSS software.

RESULTS AND DISCUSSION

3.1. Respondent Characteristics and Farming Profile

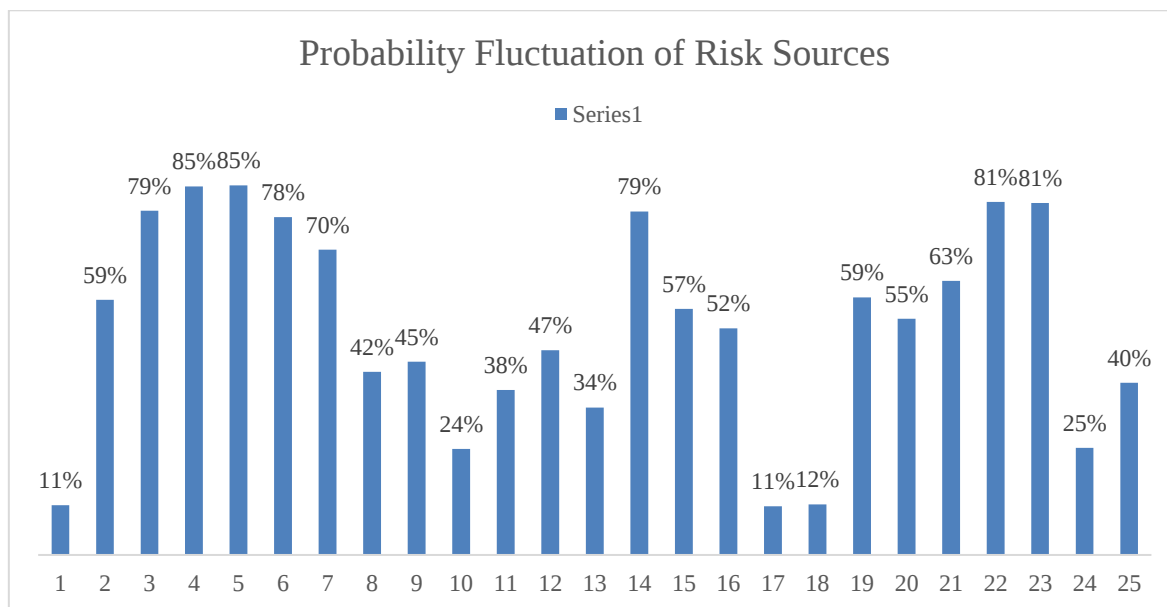
Based on the processing of primary data from 200 respondents, the primary management of coffee farming was dominated by men at 59% (household heads), with a relatively high level of female participation reaching 41%. The majority of farmers (73%) had secondary education backgrounds (junior and senior high school), which provides a favorable social capital base for adopting new technologies. The high percentage of farmers without secondary occupations (90.5%) indicates a very high level of economic dependence on coffee harvests. In terms of land profiles, land ownership was dominated by smallholders with relatively limited landholdings, ranging from 0.30 to 0.40 hectares per farmer. To diversify income risk arising from coffee fluctuations, the majority of farmers (96%) consciously applied conventional polyculture systems (intercropping) with seasonal horticultural crops such as chili, tomatoes, and oranges.

3.2. Identification of Production Risk Sources (Z-Score)

Based on the transformation of raw data using the Z-Score statistical instrument, an empirical classification was identified that proportionally divided 25 risk indicators according to occurrence thresholds. The most crucial finding at this identification stage was the deconstruction of the conventional risk paradigm, shifting from traditional upstream risks toward downstream regulatory risks. This probability fluctuation pattern indicates that Arabica coffee farmers in Karo Regency no longer perceive cultivation failure as the most urgent major threat.

Notably, the risk indicators occupying the highest hierarchy, or the "Very Frequent" category observed in the field, were dominated by modern market governance variables. Variables R4 (the requirement for products to be packaged) and R5 (the requirement for products to have a trademark) recorded the highest

positive Z-Score values, at 1.037 and 1.049, respectively, with occurrence probabilities reaching 85%. These high probabilities reflect structural pressure from modern industrial supply chains, which require market aesthetic standardization and product legality to access retail markets. This regulatory pressure is reinforced by indicators R3 (demand for ground coffee) and R22 (limited physical land available for cultivation), which recorded probabilities of 79% and 81%, respectively. This confirms that smallholder farmers in Simpang Empat District continue to face the depletion of physical land assets in highland areas, which intersects with changing consumer preferences from raw beans toward ready-to-consume processed products.



Source: Primary Data Processing

Figure 1. Probability Fluctuation of Risk Sources

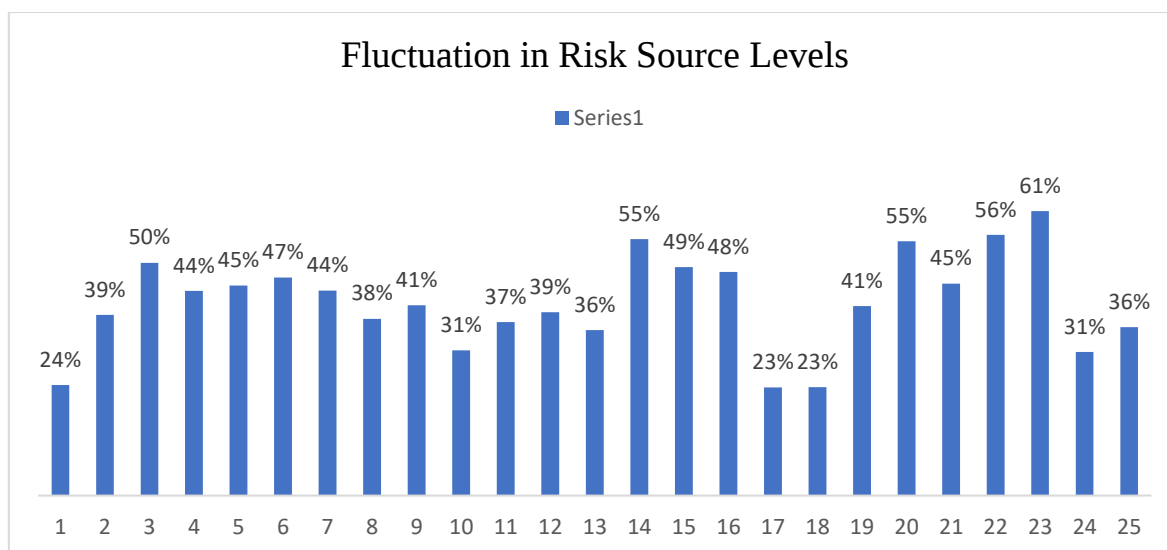
In contrast, the standardization results demonstrate that conventional upstream risks are actually within the "Very Rare" occurrence zone. Indicator R1 (a drastic decline in selling prices) has a negative Z-Score of -1.202, with the lowest occurrence probability of only 11%. This price stability is consistent with the results of the plant biological variable assessment, in which indicators R17 (plants affected by disease) and R18 (plants affected by pests) had very low probabilities, ranging from 11% to 12%. This empirical evidence challenges the assumption in previous literature that upstream pathogen attacks are consistently regarded as the most threatening risk. Natural protection in the form of the suitability of the agroclimatic conditions of volcanic Andisol soils at the foot of Mount Sinabung has proven effective in suppressing such biological volatility, keeping fluctuations below the normal threshold of farming activities.

3.3. Analysis of Production Risk Level (CV & Standard Deviation)

The relative risk level and degree of uncertainty across all coffee production activities at the research site are accurately represented by the Coefficient of Variation (CV). Based on calculations using data from 200 farmer respondents, the average productivity of Arabica coffee farming was 1.16 tons per farmer, with a relatively small average standard deviation of 0.097. This small deviation indicates that, in general, variations in production capacity among the respondent farmers in Simpang Empat District were not substantial, and the pattern tended to be relatively homogeneous.

At the aggregate regional (macro) level, the CV of Arabica coffee farming was 8.85%, with an operational loss probability of only 14.12%. According to the principles of agricultural economic risk theory,

A farming operation is categorized as having low and relatively stable risk when its coefficient of variation is below the threshold of 0.50 or 50% ($CV < 0.5$). The low average regional CV provides strong theoretical confirmation that the production fluctuations experienced by the majority of farmers in The majority of farmers in Karo Regency remain within safe and tolerable limits (acceptable risk). The certainty of harvest output is relatively well maintained over time, supported by volcanic agroecosystem conditions that are highly optimal for Arabica coffee growth.



Source: Primary Data Processing

Figure 2. Fluctuation in Risk Source Levels

CONCLUSION

At the aggregate macro level, the production risk of Arabica coffee farming in Karo Regency is categorized as low, homogeneous, and stable, with an average CV of 8.85%. The shift in the critical risk point from upstream cultivation quantity to compliance with downstream industry regulatory standards demonstrates a deconstruction of the conventional risk paradigm. To maintain the resilience of rural farming within the safe zone, policy intervention by local governments is recommended to facilitate collective trademark legalization and provide education on physical quality standards for coffee beans among traditional farmer groups.

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