



The Level of Production Risks among Smallholder Arabica Coffee Farmers Through BWM and ARP Benchmarking Methods: A Case Study in Bondowoso Regency, East Java Province

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ABSTRACT

Background: Assessing the risk levels faced by smallholder Arabica coffee farmers is essential for identifying potential threats and evaluating suitable mitigation strategies. While various studies have employed diverse methodological approaches, this research focuses on prioritizing risks and providing accurate methods for risk assessment to inform effective recommendations.

Methods: The study involved data collection from 183 participants, comprising 173 coffee farmers and 10 key informants. The evaluation of production risk levels utilized the coefficient of variation to analyze variability. Additional risk assessments were conducted using the BWM (best-worst method) and ARP (aggregate risk priority) approaches.

Result: The study revealed that the production risk level for Arabica coffee farming is moderate as perceived by farmers. A total of 33 risk events were identified, originating from 32 risk agents. Benchmarking using the BWM and ARP methods yielded differing risk prioritization outcomes for mitigation strategies. The BWM method highlighted biological and environmental risks as the most critical, whereas the ARP method identified weather-related risks as requiring immediate attention. The analysis further demonstrated that the ARP method provided more accurate risk assessment results in the context of the case study compared to the BWM method. The ARP approach identifies weather risk as the top priority for mitigation, with the highest value of 304.59 attributed to the lack of flowering and fruiting caused by low photosynthesis rates due to high cloud cover (E1).

Key words: Arabica coffee, ARP, BWM, Risk level.

INTRODUCTION

Indonesia is one of the largest coffee producers in the world, with coffee supply chains playing a critical role not only in sustaining the sector, but also in supporting the livelihoods of thousands of people (Bashiri *et al.*, 2021). Coffee production is a significant contributor to foreign exchange earnings for producing countries (Ababu and Getahun, 2021). Indonesian coffee has demonstrated high quality. Despite this success, the coffee industry has yet to reach its full potential, mainly due to challenges in supply chain management (Irlayanti and Azis, 2023).

The main approach to supply chain management is supply chain risk management (SCRM), which focuses on identifying, analyzing and addressing risks. Extending purchasing and supply chain practices to upstream suppliers is critical for sustainability and requires the implementation of robust governance mechanisms (Martinen *et al.*, 2023). Risk management is essential to minimize disruptions in the supply chain. The bottom line lies in identifying risks and understanding their root causes. Among others, risk identification is an important foundational step in the risk management process (Hallikas and Virolainen, 2024).

Agricultural risks come from various sources (Padhy *et al.*, 2024). For coffee supply chain actors, high-risk areas

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include price fluctuations, quality issues and production- and people-related risks (Paramudita and Suryaningrat, 2022). Most of these risks originate from the upstream segment of the supply chain, which then impacts downstream processes. Therefore, the focus of the supply

chain risk management analysis in this study is on farmers as the main actors in the upstream segment. The upstream segment directly affects the quality of coffee beans. Factors such as coffee varieties, cultivation techniques, harvesting and post-harvest practices largely determine the final quality of the product. The study of the upstream segment of coffee farming can provide great benefits to farmers, the coffee industry and the economy as a whole. This research introduces a novel approach by synthesizing risk sources from frameworks (Jaffee *et al.*, 2008; Tang and Nurmaya Musa, 2011; Raka and Liangrokapt, 2015).

A number of assessments have been conducted on risk issues in Arabica coffee farming in Indonesia. However, have not comprehensively addressed all coffee-producing regions, particularly in East Java Province. To fill this gap, this study focuses on coffee-producing areas in East Java, specifically Bondowoso District, aiming to identify potential risks faced by Arabica coffee farmers and provide practical solutions and recommendations for improvement. The main objective of this study is to identify and evaluate production risks and other challenges faced by coffee farmers. This paper introduces a new approach by comparing two different methods, namely the Best-Worst Method (BWM) and aggregate risk priority (ARP), to assess these risks and propose effective solutions.

MATERIALS AND METHODS

Bondowoso Regency, located in East Java, plays a pivotal role in Arabica coffee production, contributing 60% of the province's total output. Due to its significance, this research location was deliberately selected using purposive sampling. The location of the research is shown in Fig 1. The study was conducted from June 2023 to September 2024, involving a total of 183 respondents. Among them, 173 Arabica coffee farmers belonging to five Product Processing Units were selected as respondents using a total sampling technique. This selection was based on their participation in interviews to identify and assess the level of risk in coffee production. To complement these findings, direct field visits, inspections and in-depth discussions were conducted with 10 key individuals or experts to gain a comprehensive understanding of the conditions in the field. The questionnaire was targeted at 2 experienced Arabica coffee farmers with at least 10 years of experience and managing a minimum of 5 ha of land, 2 representatives from the Agriculture and Plantation Office serving as Field Agricultural Extension Workers and 2 academics invited as experts. These discussions focused on data collection and evaluating 9 identified risk levels, providing a robust basis for analyzing the challenges faced in the coffee supply chain in Bondowoso Regency.

The production risk level is evaluated through the coefficient of variation (CV) analysis. Mathematically, production risk is represented as follows:

$$CV = \frac{v}{X_i}$$

Explanation:

CV = Coefficient of variation.

v = Standard deviation.

X_i = Average.

As stated by Hernanto (1996), the criteria for interpreting the coefficient of variation (CV) are as follows: if $CV > 0.5$, the farming risk faced by the farmer increases, while if $CV < 0.5$, the farmer is likely to consistently gain profit.

Risk identification is analyzed descriptively. The sources of risk are categorized into nine types: weather risk, natural disaster risk, biological and environmental risk, market risk, logistics and infrastructure risk, management and operational risk, public policy and institutional risk, political risk and information risk. Risk assessment is carried out using two distinct methods: the Best-Worst Method (BWM) and the Aggregate Risk Priority (ARP) - House of Risk phase 1 approach.

Data processing in the BWM method is facilitated using BWM Solvers software (Rezaei, 2015). The second method, ARP, determines the risk level through the House of Risk phase 1 approach (Pujawan and Geraldin, 2009). Microsoft Excel can be used as a tool to assist in this process. The Aggregate Risk Potential (ARP) value is calculated to help prioritize risk mitigation efforts. The formula for calculating ARP is as follows:

$$ARP_j = O_j \sum S_i R_{ij}$$

Explanation

ARP_j = Aggregate risk potential.

O_j = Occurrence level of risk agent.

S_i = Severity level of risk event.

R_{ij} = Degree of connection between risk agent (j) and risk event (i).

RESULTS AND DISCUSSION

Production risk for smallholder arabica coffee farmers

Production risk is a common challenge in the agricultural sector, often arising from unpredictable factors such as weather conditions, pests and diseases. The level of risk can be quantified using the coefficient of variation, which requires calculating the standard deviation first. The extent of production risk for coffee farmers in Bondowoso Regency is presented in the Table 1.

Production risk refers to the uncertainty surrounding agricultural output, where changes in the quantity and quality of production pose potential risks (Puryantoro *et al.*, 2024). The average production reported by the respondent farmers

Table 1: Coefficient of variation values for the risk of Arabica coffee production.

Description	Production (kg)
Average	7431.39
Standard deviation	5013.69
Coefficient of variation	0.67

Source: Primary data, 2024.

is 7.431.39 kg, with a standard deviation of 5.013.69. The coefficient of variation for Arabica coffee production is 0.67, indicating a moderate level of risk, as the CV value exceeds 0.5. This suggests that the risk in Arabica coffee farming in Bondowoso Regency outweighs the profit gained by farmers.

Production risks in Arabica coffee farming in Bondowoso are high due to extreme weather, pests, limited technology and high costs. Despite its high value, farmer profits often fail to cover these risks. Climate changes and pest outbreaks reduce yields, with 35% to 75% of plantations potentially becoming unviable this century (Etana and Merga, 2023; Degefa, 2024; Dias *et al.*, 2023).

Supply chain risk identification

Based on the focus group discussion (FGD) several risks were identified in the coffee agribusiness activities of the local community. These risks were determined by examining the risk events experienced by the farmers and their underlying causes (risk agents). A total of 33 risk events have been identified among farmers, spread across nine risk sources. As depicted in Fig 1, management and

operational risks account for the highest number of incidents, with six occurrences. A total of 33 risk events were identified among farmers, spread across nine risk sources. As depicted in Fig 2, management and operational risks accounted for the highest number of incidents, with six risk events. The first risk event is pruning that is not done according to the Standard Operating Procedure (SOP), which should be done three times a year to maintain plant health and optimal yields. The second risk event, weeding, can lead to competition for nutrients and an increased risk of pest attacks. The third risk event relates to the use of seedlings of origin, while the fourth risk event, non-uniform seedling varieties, can hinder uniformity of growth and yield quality. On the managerial side, the fifth risk event is the absence of farm cash flow bookkeeping. Finally, the sixth risk event, coffee theft in the field, is a frequent threat experienced by farmers, resulting in financial losses. In contrast, sources of political risk, information risk, logistics risk and infrastructure risk each had the lowest number of incidents, with only two each. In contrast, political risk, information risk, logistics risk and infrastructure risk

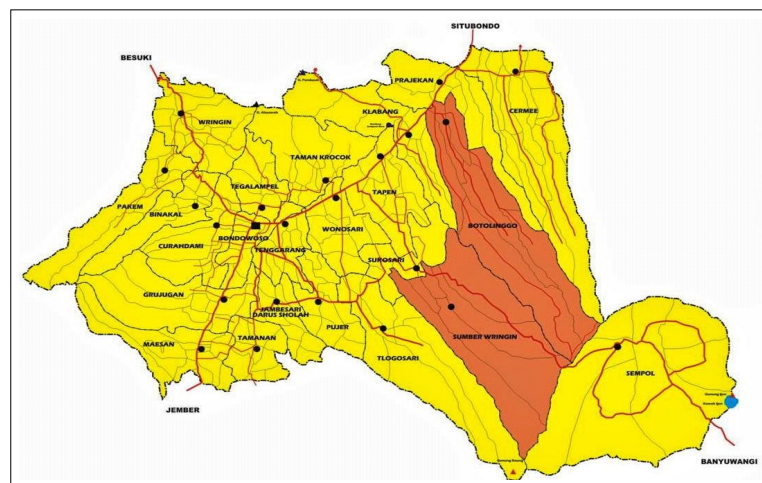


Fig 1: Map of research location.

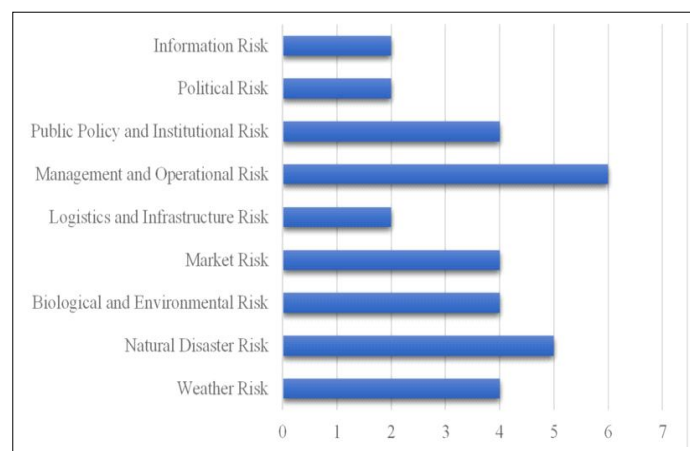


Fig 2: Number of risk events for Arabica coffee farmers.

sources each have the lowest number of incidents, with only two occurrences each.

The identified risk events among farmers are caused by a variety of risk agents. Each risk event may result from disturbances by one or more risk agents and similarly, each risk agent can lead to multiple risk events (Pujawan and Geraldin, 2009). The identification of risk agents among coffee farmers reveals 32 risk agents, which cause a total of 33 risk events, as presented in Table 2.

Risk level of the smallholder arabica coffee supply chain

The risk level of the Arabica coffee supply chain was assessed using two analytical approaches: the Best-Worst Method (BWM) and the Aggregate Risk Potential (ARP) method. The analysis revealed three risk sources with consistent risk level values across both approaches: natural disaster risk, logistics and infrastructure risk and

public policy risk. However, six risk sources showed differing risk level values between the two methods. These include weather risk, biological and environmental risk, market risk, management and operational risk, political risk and information risk, as detailed in Table 3.

The benchmarking results of risk level assessment using the BWM The risk level of the Arabica coffee supply chain was assessed using two analytical approaches: The best-worst method (BWM) and the aggregate risk potential (ARP) method. The analysis revealed three risk sources with consistent risk level values across both approaches: natural disaster risk, logistics and infrastructure risk and public policy risk. However, six risk sources showed differing risk level values between the two methods. These include weather risk, biological and environmental risk, market risk, management and operational risk, political risk and information risk, as detailed in Table 3.

Table 2: Risk agent for Arabica coffee farmers.

Source of cause (risk agent)	Code
1. Extreme weather, such as heavy rain or prolonged thick clouds	A1
2. Very high rainfall or continuous heavy rain can cause excessive water flow	A2
3. Unsuitable climate conditions, such as extreme temperatures or large temperature fluctuations, can affect plant health and seed quality	A3
4. Diseases like coffee leaf rust (<i>Hemileia vastatrix</i>) or coffee berry disease (<i>Colletotrichum kahawae</i>) can cause leaves and branches to dry out and disrupt the formation and filling of coffee beans	A4
5. Human activities such as land clearing for agricultural areas or burning waste	A5
6. Excessive use of pesticides and herbicides	A6
7. Limited coffee production	A7
8. No sales contracts yet	A8
9. Urgent financial needs of farmers' households	A9
10. Financial constraints of buyers	A10
11. Limitations in market access	A11
12. Coffee plantation locations far from distribution centers	A12
13. The rise in fuel prices directly affects transportation costs	A13
14. Difficult geographical conditions	A14
15. Minimal infrastructure near the plantations	A15
16. Lack of knowledge or training for farmers	A16
17. Limited labor force	A17
18. Minimal supervision or technical assistance	A18
19. Dependence on chemical herbicides	A19
20. The high price of superior seeds and the lack of supervision or certification	A20
21. Dependence on local seeds or traditional heritage	A21
22. Limited capital and resources	A22
23. Lack of knowledge about financial management	A23
24. Lack of security in plantation areas and the economic motivation of thieves	A24
25. Strict credit criteria with high interest rates	A25
26. Rental policies determined by forestry	A26
27. Lack of participation from farmer group members	A27
28. Changes in leadership or administration	A28
29. International trade policies	A29
30. Political instability in the export destination country	A30
31. Lack of geographical accessibility	A31
32. Cyber attacks or hacking	A32

Source: Primary data, 2024.

The benchmarking results of risk level assessment using the BWM and ARP - HOR 1 methods indicate differing values for priority risks that require immediate attention. Based on Table 3, the priority risk identified through BWM analysis is event E11, while ARP analysis highlights event E1 as the priority risk for coffee farmers to address urgently. According to the BWM analysis, the top-ranked risk is high nutrient leaching causing damage to nutrient-poor soil under the biological and environmental risk source. In contrast, the ARP analysis ranks the lack of flowering and fruiting due to a low photosynthesis rate caused by high cloud cover under the weather risk source as the highest priority.

The BWM method identifies biological and environmental risk as the highest priority for mitigation, particularly the significant risk of nutrient leaching that leads to damage in nutrient-poor soil (E11), with a score of 3.771. Conversely, information risk ranks the lowest, with a score of 0.543, specifically in cases of delays or unavailability of information and communication infrastructure (E32). The ARP approach (HOR 1) ranks weather risk highest (304.59), mainly due to reduced flowering from low photosynthesis (E1), while management risks like missed weeding (E21) are lowest. Weather directly affects 50% of food production and 30% indirectly (Meena *et al.*, 2018), influencing pest

Table 3: Weighted risk level results for smallholder arabica coffee farmers.

Source of risk	Risk event	BWM	ARP
Weather risk	1. Reduced flowering and fruiting caused by a low photosynthesis rate due to prolonged high cloud cover (E1).	2.655	304.59
	2. Accelerated fruit ripening, leading to a decline in fruit quality (E2).	1.933	129.6
	3. Tree damage and premature fruit drop before harvest (E3).	2.595	147.936
	4. Limited sunlight exposure, reducing crop growth intensity (E4).	2.817	291.72
Natural disaster risk	1. Flash floods affecting the coffee plantation (E5).	1.473	129.6
	2. Fires damaging the coffee plantation (E6).	2.209	222.3
	3. Erosion and landslides impacting plantation areas (E7).	1.653	108.192
	4. Drying of leaves and branches, accompanied by an increase in empty seeds (E8).	2.374	248.82
Biological and environmental risk	5. Higher mortality rates among young coffee plants (E9)	2.291	116.64
	1. Diseases caused by fungi and pests, such as the coffee berry borer (E10).	2.703	90.552
	2. High nutrient leaching leading to degradation of nutrient-poor soil (E11).	3.771	118.818
	3. Environmental pollution and the depletion of natural resources (E12).	1.819	268.8
Market risk	4. Contamination affecting humans and causing diseases (E13).	1.707	168.84
	1. Unmet demand for green bean products (E14).	2.201	300.3
	2. Fluctuations in the demand for green bean products (E15).	1.560	176.32
	3. Extended payment periods for green beans (E16).	2.586	258.75
Logistics and infrastructure risk	4. Farmers' inability to set the selling price (E17).	3.653	262.656
	1. High transportation costs (E18).	1.549	162.792
	2. Poor communication signals in coffee plantation areas (E19).	1.188	39.672
	1. Pruning not performed according to the standard operating procedure (SOP) of three times a year (E20).	2.596	114.912
Management and operational risk	2. Lack of weeding practices (E21).	1.438	18.9
	3. Use of uncertified or unverified seedlings (E22).	1.340	47.736
	4. Inconsistent use of seedling varieties (E23).	1.456	76.328
	5. Absence of farm cash flow bookkeeping (E24).	0.954	119.04
Public Policy and institutional risk	6. Incidents of coffee theft on the plantation (E25).	2.216	242.048
	1. Limited financial institutions available to support farmers (E26).	3.582	234.36
	2. High costs associated with renting the State Forestry Public Company's land (E27).	2.667	156.6
	3. Inactive or non-functioning farmer groups (E28).	2.706	153.468
Political risk	4. Uncertainty in local government policies regarding priority flagship production (E29).	1.045	172.584
	1. Competition risks from imported coffee (E30).	2.239	194.568
Information risk	2. Conflicts in coffee export destination countries (E31).	3.058	132.3
	1. Delay or unavailability of information and communication infrastructure (E32)	0.543	32.148
	2. Damage to external/internal IT infrastructure (E33)	1.423	24.024

Source: Primary data, 2024.

Table 4: Benchmarking accuracy of BWM and ARP-HOR 1.

Accuracy aspect	BWM	ARP
The relationship between risk events and risk causes	Not considered	Considered in depth
Scope of risk	Limited number of risks	Unlimited risks

Source: Primary data, 2024.

dynamics and coffee quality, including aroma and taste (Maneerat *et al.*, 2024).

Case study: Application of bwm and ARP - HOR 1 methods for coffee farmers

The BWM method's final weighting is considered more reliable than the AHP method due to its higher consistency (Priyati *et al.*, 2022). BWM is also easier to implement, requiring fewer preference comparisons. It involves prioritizing the best criteria over all others and comparing all criteria to the worst, with values ranging from 1 to 9. According to Agyemang *et al.* (2022), BWM is advantageous as it requires less data and computing time than AHP methods. Furthermore, it is more consistent than other Multi-Criteria Decision-Making (MCDM) methods that rely on pairwise comparison matrices (Qarnain *et al.*, 2020; Shukla *et al.*, 2021). Gupta and Barua (2017) corroborate this by comparing BWM and AHP results, finding BWM to be more consistent and accurate.

The BWM method outperforms AHP in terms of consistency ratio and other evaluation metrics, such as minimum violation, total deviation and conformance. Key advantages of BWM over traditional MCDM methods include: (1) its requirement for less comparative data and (2) its ability to generate more consistent comparisons, leading to more reliable results (Rezaei, 2015).

This study confirms that BWM is easier to use than AHP but less effective when analyzing fewer than three risks. It suggests combining risk sources in such cases and simplifying the process for more than nine risks. These limitations may reduce accuracy, as BWM requires direct comparisons, potentially leading to biased results that overlook risk interrelationships.

As shown in Table 4, unlike the assessment of risk levels using ARP-HOR 1, ARP evaluates the impact of risks, the probability of risk events and the connection between risk events and their causes. This comprehensive approach enables ARP-HOR to deliver more proportional and precise weightings. By factoring in hierarchical relationships, it accounts for the relative importance of each criterion, resulting in outcomes that are more balanced and reflective of real-world conditions.

CONCLUSION

Arabica coffee farmers in Bondowoso face significant risks, even though the coefficient of variation categorizes them as moderate.

Extreme climate, pest and disease attacks, and high production costs worsen production risks. Limited access to technology and financing reduces opportunities to improve productivity. A total of 33 risk events are linked to 32 risk sources affecting the farmers. The BWM method ranks nutrient leaching (E11) as the highest risk, while ARP places risk E1 at the top. ARP is considered more flexible and accurate due to its consideration of cause-effect relationships. Future studies should involve other supply chain actors and explore alternative benchmarking methods

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Conflict of interest

We, the collective authors of this research, declare that we do not have any conflicts of interest related to this research. We do not have any financial interests, personal relationships, or any other factors that could affect the impartiality and objectivity of this research. We also affirm that we will conduct this research in accordance with the highest ethical standards and in accordance with all relevant institutional or organizational policies.

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