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Risk Analysis of Greenhouse-Based Paprika Farming Using Failure Mode and Effect Analysis (FMEA)

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ABSTRACT

Bell pepper is a high-value horticultural commodity with strong development potential in Indonesia, including in Tutur District, Pasuruan Regency, East Java. However, productivity in greenhouse-based cultivation often fluctuates due to various production risks. This study aimed to identify and prioritize major risks in greenhouse bell pepper farming using the Failure Mode and Effect Analysis (FMEA) method. The research location was purposively selected, involving 66 farmers. Primary and secondary data were collected and analyzed using descriptive analysis and FMEA. The results identified 17 risk factors affecting bell pepper production. Major risks included high rainfall during the rainy season, water shortages during the dry season, strong winds, pest and disease attacks, declining selling prices, increasing input costs, and limited technical knowledge. Based on Risk Priority Number (RPN) analysis, the most critical risks were thrips pest attacks (RPN 109.12), high rainfall (RPN 52.52), and strong winds (RPN 38.31). These risks require priority mitigation to improve productivity and sustainability of greenhouse bell pepper farming.

1. INTRODUCTION

Indonesia is one of the countries with high biodiversity, both in flora and fauna. This is supported by its geographical location in the tropics, with a climate that favors the growth of a wide variety of plants and animals (Sudaryat, 2020). Fertile soil is a crucial factor that makes Indonesia an ideal environment for the growth and development of various plant species, including horticultural crops. One vegetable commodity that plays a significant role in agricultural development is paprika (Sulistyaningsih et al., 2022).

Paprika (*Capsicum annuum* L.) belongs to the chili family but has varying levels of spiciness. Its fruits come in a range of colors, such as green, yellow, red, and purple, and are commonly used as ingredients in salads. Although aromatically similar to chili peppers, paprika is not spicy and is predominantly sweet, hence the name sweet pepper. Chili plants generally have a spicy taste, but paprika is a chili variety that does not have a spicy taste (Aviantara & Sarjana, 2019). Typical hot chili peppers have a spiciness level of 25,000–50,000 SHU (UF/IFAS, 2025), whereas paprika ranges from only 0–500 SHU (Scoville Heat Units).

Paprika is generally grown in greenhouses because it is sensitive to direct sunlight. In this agricultural system, it is often cultivated hydroponically, a method that relies mainly on water. A major advantage of this approach is its efficient use of space, allowing limited land to be utilized optimally for productive farming activities (Murtadho *et al.*, 2021). As a foreign vegetable commodity with high development potential in Indonesia, paprika also has significant economic value (Ramadhanty *et al.*, 2020). This is reflected in the increasing demand for paprika, especially in hotels and big restaurants due to improvements in people's lifestyles (Nurcahyani & Iqbal, 2014).). Paprika therefore has very promising prospects, both for meeting local demand and for export. Recognizing this opportunity, many farmers are motivated to learn effective cultivation techniques and expand paprika production. These efforts aim to improve farming success and support agribusiness development at the farmer level. Production can increase if cultivation systems are implemented correctly and efficiently.

As a horticultural commodity with high market potential, paprika is grown in various regions across Indonesia. East Java is one of the important producer of paprika in Indonesia. Based on BPS data on paprika production in East Jawa has fluctuated from year 2019 to 2023 (Figure 1). The lowest harvest occurred in 2021, totalling 7781 tons from 320 hectares, while the highest was recorded in 2022, with 17,517 tons produced on 548 hectares (BPS, 2024). One of the important paprika-producing areas in East Java is Pasuruan Regency, especialy Tutur District.

Paprika cultivation continues to face various risks, including production, price, financial, institutional, and human resource risks (Usman *et al*., 2017). In Tutur District, one example of production risk is influenced by several agronomic and environmental factors, particularly extreme weather conditions (Putri *et al*., 2024). Situated in a highland area, Tutur experiences relatively high rainfall, especially during the rainy season. This increases air and soil humidity significantly, creating a very humid environment that directly affects paprika crop productivity.

However, not all risks need to be prioritized for management, considering farmers' limited resources and time for implementing mitigation strategies. Therefore, it is crucial to identify the main sources of risk in paprika farming, which generally fall into five categories: (1) production, (2) price fluctuations, (3) financial aspects, (4) institutional aspects, and (5) human resources.

To gain a deeper understanding and determine priority areas for intervention, this study aims to analyze the sources of risk in greenhouse-based paprika cultivation using the FMEA method. This analysis takes into account the specific characteristics of paprika, which differ from other horticultural commodities such as chili or tomatoes. Unlike paprika, chili and tomatoes can generally be grown in open fields with relatively simple inputs, whereas paprika requires greenhouse cultivation due to its high sensitivity to climatic conditions. Additionally, paprika farming demands larger investments in production facilities and more intensive care, resulting in a more complex risk profile compared to other horticultural commodities.

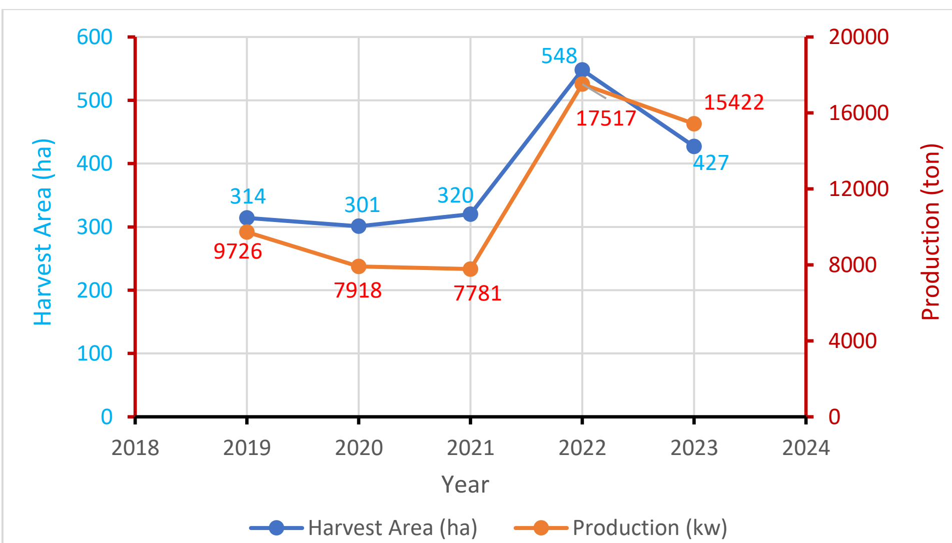

Figure 1. Harvest area and production of paprika in East Java (BPS, 2024)

2. MATERIALS AND METHODS

This research was conducted in Tutur District, Pasuruan Regency, from March to April 2025. Data collection tools included a questionnaire as the primary instrument, supported by stationery and a mobile phone to assist in recording responses and interviews. The study involved 66 paprika farmers who use greenhouses in Tutur District. Respondents were selected using purposive sampling based on the following criteria: (1) actively cultivating paprika in greenhouses, (2) having at least three years of experience in paprika farming, and (3) willing to participate in interviews and provide the required information.

This study used two types of data: primary and secondary. Primary data were obtained through field surveys and in-depth interviews with the farmers, while secondary data were collected from relevant written sources, including scientific journals, articles, books, and data from the Central Statistics Agency (BPS) of Pasuruan Regency and other relevant institutions.

2.1. FMEA (Failure Mode and Effect Analysis) Method

Failure Mode and Effect Analysis (FMEA) is a systematic approach used to identify and evaluate the likelihood of potential failures and their consequences, with the aim of mitigating risks at an early stage (Alijoyo *et al*., 2020). This method relies on three main parameters: severity, probability of occurrence, and detection rate. These parameters are then multiplied to obtain the highest priority value, known as the Risk Priority Number (RPN) (Noor, 2022).

All risks are assessed based on a predetermined scoring system. In this study, the assessment criteria ranged from 1 to 5, as detailed in Table 1. The risk priority for each identified issue was then calculated using the RPN (Risk Priority Number) as detailed in Equation (1) with *S* is severity value, *O* is *O*ccurrence level value, and *D* is detection value.

$$RPN = S \times O \times D \tag{1}$$

Table 1. FMEA assessment indicators (Firnanda *et al*., 2023)

Score	Risk Assessment Indicator		Criteria
1	Occurrence	Never	Almost certainly will not occur, probability 10–20%
2		Rare	Very unlikely to occur, probability 30–40%
3		Fairly frequent	May or may not occur, probability 50%
4		Frequent	Will occur, probability 70–80%
5		Very frequent	Almost certain to occur, probability 90–100%
1	Severity	No impact	Causes no effect, almost never (none)
2		Slight impact	Slightly causes an effect, resulting impact (low)
3		Moderate impact	Moderately causes an effect (moderate)
4		High impact	Strongly causes an effect (high)
5		Detrimental	Very detrimental (very high)
1	Detection	Certainly detected	This detection method is highly effective and ensures early identification of risks for implementing contingency plans.
2		Easily detected	The detection approach shows significant effectiveness, with the probability of occurrence of the cause at a minimal level.
3		Fairly easy to detect	The detection method has an average level of effectiveness (medium); the cause occasionally recurs.
4		Difficult to detect	The detection method is unproven or unreliable, or its effectiveness is unknown for timely detection; the factor tends to recur.
5		Cannot be detected	No adequate detection mechanism available; existing methods cannot provide sufficient time for contingency strategy implementation, so the cause tends to recur.

3. RESULTS AND DISCUSSION

3.1. Respondent Characteristics

A farmer is defined broadly as an individual engaged in the agricultural sector, including farming, livestock, fisheries, and forestry. The respondents in this study were paprika farmers in Tutur District, Pasuruan Regency, who had been actively cultivating paprika for at least three years and were familiar with its cultivation practices.

Primary data collected through questionnaires revealed respondent characteristics, including age, education level, land area, land ownership status, and farming experience. Table 2 presents the age distribution of respondents in this study. The majority of farmers, 51 individuals (77.27%), were between 31 and 50 years old. This indicates that most paprika farmers are in the productive age group, which can influence decision-making, particularly in choosing the cultivation systems to be applied in their farming operations. Farmers in this age range generally have better physical capabilities and higher adaptability to new agricultural technologies.

Table 2. Characteristics of paprika farmers in Tutur Sub-district

No.	Category	Number	Percentage (%)
1.	**Age (years)**		
	<30	9	13.64
	31–50	51	77.27
	>50	6	9.09
2.	**Education**		
	Elementary School	1	1.52
	Junior High School	9	13.64
	Senior High School	52	78.78
	University	4	6.06
3.	**Land Area (Ha)**		
	0–0.1	31	46.96
	0.1–0.3	33	50.00
	>0.3	2	3.03
4.	**Land Ownership**		
	Rented	24	36.36
	Owned	42	63.63
5.	**Farming Experience (years)**		
	3–8	18	27.27
	9–14	44	66.67
	>14	4	6.06

The table also shows that the majority of paprika farmers in Tutur District have a high level of education, with 52 farmers (78.78%) holding a high school diploma. This suggests that most farmers are well-educated, facilitating the absorption of information, technology, and new innovations, especially in modern greenhouse-based farming systems. Adequate education supports better technology adoption, which positively impacts farming efficiency and productivity.

Land area refers to the total plot used for paprika cultivation. Most farmers cultivate on small plots, with 50% owning between 0.1 and 0.3 hectares. The limited land size is largely due to the high cost of greenhouse construction, which is essential for paprika farming.

Land ownership status also plays a significant role in farming decisions. As shown in Table 2, the majority of farmers (63.63%) manage their own land, providing greater flexibility in decision-making and higher potential profits compared to rented land. The remaining 36.36% of farmers rent land to expand their planting area, compensating for limited private land and aiming to increase production.

Farming experience is a key factor in the success of paprika cultivation. The data indicate that most farmers (44 individuals, 66.66%) have 9–14 years of experience. Farmers with more than nine years of experience are likely to have effective farm management skills and a better understanding of overcoming challenges. This highlights the relationship between farming experience and the ability to plan and mitigate risks. Experienced farmers also tend to have more practical knowledge regarding climate conditions, pest management, and market price dynamics (Wulandari *et al*., 2020).

3.2. Identifying Risk Sources in Paprika Farming

Paprika farming inherently involves various operational risks. These risks may stem from both external and internal factors that can affect the smooth running of production processes and the overall sustainability of the farming business. The risks in paprika cultivation are interrelated and, if not properly managed, can threaten business continuity. Production risks, such as pest infestations and climate variability, can lead to reduced yields. These fluctuations in production subsequently trigger price risks, as unstable output affects market stability and ultimately impacts farmers' income. The situation is further compounded when agricultural institutions are not functioning effectively, and farmers have limited skills or experience in managing these challenges.

3.2.1. Production Risk

Based on Table 3 regarding production risks, the risk source associated with thrips attacks has the highest RPN value, at 109.12, followed by high rainfall caused by the rainy season, with an RPN of 52.52. Production risks faced by paprika farmers in Tutur District, Pasuruan Regency, are primarily caused by physical factors such as natural conditions. These risks directly impact production levels and farmer income, as agricultural cultivation is highly dependent on external factors such as weather, pests, temperature, drought, and flooding (Sinaga *et al*., 2025).

Table 3. Production risks of paprika cultivation in Tutur District

No.	Source of Risk	Occurrence	Severity	Detection	RPN
1.	High rainfall due to the rainy season	3.30	3.61	4.41	52.52
2.	Water shortage due to the dry season	1.59	1.36	3.80	8.25
3.	Strong winds	3.03	2.67	4.74	38.32
4.	Fruit rot disease attack	2.32	2.15	2.80	13.98
5.	Aphid (whitefly) pest attack	2.71	3.11	3.56	29.99
6.	Stem rot attack	2.47	2.89	3.30	23.61
7.	Root rot disease attack	2.12	2.03	2.88	12.40
8.	Thrips pest attack	4.92	4.92	4.50	109.12

3.2.2. Price Risk

Based on Table 4 regarding price risk, the source of risk with the highest value is indicated by declining prices due to declining paprika quality, with an RPN value of 32.58. In paprika farming, price fluctuations are one of the main risks faced by farmers. This risk includes changes in input and output prices and is influenced by market demand, seasonality, and competition from imported products (Murtadlo, 2023). Price instability causes uncertain farmer incomes. Furthermore, declining harvest quality due to pest and disease attacks can also lower paprika selling prices.

Table 4. Price risks for paprika cultivation in Tutur District

No.	Source of Risk	Occurrence	Severity	Detection	RPN
1.	Price decline due to paprika harvest season	2.62	2.83	2.61	19.35
2.	Price decrease due to declining chili quality	2.74	2.97	4.00	32.58
3.	High prices of fertilizers and pesticides	2.42	2.88	2.23	15.54

3.2.3. Financial/Income Risks

Paprika cultivation businesses face financial risks influenced by fluctuations in input and output prices. Table 5 shows that uncertain selling prices, with the highest RPN value (15.75), are generally caused by peak harvests, fluctuating demand, competition from imported products, and declining paprika quality due to pests or disease. These conditions contribute to unstable farmer incomes (Amri *et al.*, 2022).

Table 5. Financial or income risks of paprika cultivation in Tutur District

No.	Source of Risk	Occurrence	Severity	Detection	RPN
1.	Uncertain selling price of paprika	3.00	3.50	1.50	15.75
2.	Harvest yield cannot cover capital borrowed from third parties	0.98	0.98	3.65	3.54
3.	Production results cannot cover operational costs	0.98	0.98	3.65	3.54

3.2.4. Institutional Risk

Agricultural extension workers play a crucial role in disseminating cultivation technology, but their role for paprika farmers in Tutur District remains limited (Table 6) because paprika is not included in the nine national strategic commodities. Consequently, farmers do not receive government support such as subsidies, training, or empowerment programs. However, farmers within farmer groups can still access information through knowledge exchange among members. Conversely, farmers outside farmer groups tend to have difficulty obtaining cultivation information because they lack access to such forums (Amri *et al.*, 2022).

Table 6. Institutional risks of paprika cultivation in Tutur District

No.	Source of Risk	Occurrence	Severity	Detection	RPN
1.	The role of agricultural extension officers in the paprika cultivation process	2.70	1.24	2.64	8.83
2.	Non-participation in farmer groups	2.00	3.00	2.00	12.00

3.2.5. Human Resource Risks

Unskilled labor is not a problem or risk for paprika farmers in Tutur District, as the majority of them have extensive farming experience. Table 7 shows that one risk is farmers' lack of knowledge regarding farm financial management. This irregularity in financial administration can make it difficult for farmers to evaluate business performance, both in terms of profit and loss, and potential for business development.

Table 7. Human resource risks of paprika cultivation in Tutur District

No.	Source of Risk	Occurrence	Severity	Detection	RPN
1.	Unskilled labor	1.75	1.50	1.00	2.62
2.	Lack of knowledge in financial management	2.10	1.50	3.00	9.45

Analysis of Paprika Farming Risk Priorities

Table 8 shows that the risk source for thrips (*Frankliniella occidentalis*) attacks has the highest RPN value of 109.12. The second highest is high rainfall caused by the rainy season with an RPN of 52.52, and the third highest is strong winds with an RPN of 38.32. The highest RPN values indicate that these risks are a top priority for risk management.

Table 8. Risk priority number (RPN) assessment on paprika farming

Source of Risk	Severity	Occurrence	Detection	RPN	Rank
Thrips pest attack	**4.92**	**4.92**	**4.50**	**109.12**	**1**
High rainfall due to the rainy season	**3.30**	**3.61**	**4.41**	**52.52**	**2**
Strong winds	**3.03**	**2.67**	**4.74**	**38.32**	**3**
Price decline due to reduced paprika quality	2.74	2.97	4.00	32.58	4
Aphid (whitefly) pest attack	2.71	3.11	3.56	29.99	5
Stem rot attack	2.47	2.89	3.30	23.61	6
Price decrease due to paprika harvest season	2.62	2.83	2.61	19.35	7
Uncertain selling price of paprika	3.00	3.50	1.50	15.75	8
High prices of fertilizers and pesticides	2.42	2.88	2.23	15.54	9
Fruit rot disease attack	2.32	2.15	2.80	13.98	10
Root rot disease attack	2.12	2.03	2.88	12.40	11
Non-participation in farmer groups	2.00	3.00	2.00	12.00	12
Lack of knowledge in financial management	2.10	1.50	3.00	9.45	13
The role of farm extension officers in the paprika cultivation process	2.70	1.24	2.64	8.83	14
Water shortage due to the dry season	1.59	1.36	3.80	8.25	15
Harvest yield cannot cover capital borrowed from third parties	0.98	0.98	3.65	3.54	16
Production results cannot cover operational costs	0.98	0.98	3.65	3.54	17
Unskilled labor	1.75	1.50	1.00	2.62	18

Thrips are a major pest in paprika cultivation, causing significant damage, especially during the generative phase of the plant. Initial attacks usually occur on young fruit, causing lesions on the fruit surface and reducing harvest quality. Thrips also attack young leaves, causing silvery spots, discoloration, and tissue damage. They can also damage plant shoots, which play a crucial role in growth and branch formation (Inaya *et al*., 2022). Thrips reproduce rapidly in greenhouse environments with high humidity and limited circulation, causing damage to both leaves and paprika fruit.

Thrips attacks not only reduce the appearance of the fruit but also directly impact the selling price, which can drop drastically. This situation differs from other horticultural commodities, such as chili peppers or tomatoes, where the main risks are more often related to wilting or fruit rot. This difference indicates that in paprika farming, thrips control is a top priority. Thrips control strategies for paprika plants in Tutur District include removing infected plant debris and diseased leaves to reduce the pest's habitat, as well as maintaining cleanliness around the plants (Prihatiningrum, *et al*., 2021). In addition to routine monitoring and natural methods, farmers also use insecticides containing the active ingredient abamectin, which effectively damages the nervous system and metabolism of pests (Kleruk *et al*., 2024). Pesticide applications are carried out routinely every afternoon as part of integrated pest management.

High rainfall can increase air and soil humidity in and around the cultivation area, especially in greenhouse systems that lack optimal drainage or ventilation. This high humidity risks triggering stem rot in paprika plants, caused by pathogens such as Phytophthora capsici or other fungi that thrive in humid conditions (Heviyanti *et al*., 2021). This disease can cause plant stems to rot, leaves to wilt, and reduced productivity, even to plant death. To address this, paprika farmers in Tutur District use the fungicide Previcur as a control measure (Supriatna & Azzahra, 2021), and significantly increase the intensity of pesticide and fungicide applications during the rainy season. In an effort to prevent further crop damage and maintain the quality and quantity of the harvest, farmers feel the need to increase the dosage and frequency of pesticide and fungicide spraying during periods of high rainfall.

Strong winds are a significant risk factor in greenhouse paprika cultivation, as they can damage physical structures such as protective plastic and frames, reducing the stability of the microclimate's temperature and humidity (Lestari *et al*., (2024). Furthermore, strong winds can cause mechanical damage to plants and disrupt pollination, increasing susceptibility to pests and diseases (Ardiansyah *et al*., 2024). This risk can be managed through strengthening the physical structure and improving greenhouse design by using sturdy, wind-resistant materials (Suud, 2023). Greenhouse design also plays a crucial role in mitigating the risk of strong winds. A saw-teeth roof is recommended because it improves air circulation, reduces wind pressure, and stabilizes temperature and humidity, creating optimal microclimate conditions for paprika. A design that adapts to weather and wind direction is also important, as it also helps control pests and diseases. Regular maintenance, such as cleaning and structural inspections, is necessary to prevent damage and maintain production sustainability. Furthermore, the role of the government or agricultural extension workers in Tutur District in supporting paprika farmers is still lacking. This is because paprika is not included in the nine national strategic agricultural commodities. As a result, paprika farmers do not receive support or assistance from government, whether in form of subsidies, training, or access to agricultural empowerment programs.

4. CONCLUSION

Palm farmers in Tutur District face five sources of risk: production, price, financial, institutional, and human resources, totaling 18 risk factors. The three main risks include thrips attacks, high rainfall that causes stem rot, and strong winds that damage greenhouses. Therefore, mitigation strategies are needed, such as implementing integrated pest management (IPM), using disease-resistant varieties, improving greenhouse design to be more wind-resistant and able to regulate humidity, and strengthening farmer institutions to strengthen their bargaining power over market prices. The local government can also play a role through technical training, subsidies for production inputs, and easier access to financing, thereby mitigating risks and ensuring the sustainability of paprika farming.

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AUTHOR CONTRIBUTION STATEMENT

Author	C	M	So	Va	Fo	I	R	D	O	E	Vi	Su	P	Fu
ESS	✓	✓		✓	✓	✓		✓	✓	✓	✓			✓
TS	✓	✓		✓	✓		✓			✓		✓		
SW	✓			✓	✓		✓			✓		✓		

C: Conceptualization	Fo: Formal Analysis	O: Writing - Original Draft	Fu: Funding Acquisition
M: Methodology	I: Investigation	E: Writing - Review & Editing	P: Project Administration
So: Software	D: Data Curation	Vi: Visualization	
Va: Validation	R: Resources	Su: Supervision	

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