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Optimizing Straw Mushroom Production through Risk-Based Decision-Making: Insights from the House of Risk Approach

Muhamad Dziaul Fadli[1], Novi Diah Wulandari[2]*, Nurna Pratiwi[3]

[1,2,3] *Faculty of Economics, Universitas Nahdlatul Ulama Yogyakarta, Yogyakarta, Indonesia*
**Corresponding author: Novi Diah Wulandari*
Corresponding email: d.wulandari@unu-jogja.ac.id

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ABSTRACT
Risk of production in straw mushroom cultivation has become a critical concern due to its vulnerability to environmental fluctuations, pathogen contamination, and unstable market conditions. These risks have led to declining yields and quality, particularly for smallholder enterprises in Indonesia. This study aims to analyze the risks in straw mushroom production at Oemah Jamur using the House of Risk (HOR) model while also examining the role of digital tools in mitigating priority risks. The research employed a mixed-methods approach by integrating interviews, field observations, and secondary data to identify potential risk events. The HOR model was applied in two stages: first, to map and quantify risk agents using Aggregate Risk Potential (ARP), and second, to prioritize mitigation actions based on their effectiveness-to-difficulty ratio. Data triangulation was used to strengthen the validity of findings, and Pareto analysis was employed to highlight the most influential risks. The process enabled systematic identification of 13 risk events and 16 risk agents, leading to the determination of 10 priority risks. The main results show that fluctuations in temperature, humidity, and lighting were the most critical risks, and the adoption of an automatic climate control system offered the most effective mitigation. Additionally, IoT-based monitoring, standardization of pasteurization, and improved ventilation significantly enhanced environmental stability. These findings imply that combining structured risk analysis with digital solutions can improve the efficiency, sustainability, and competitiveness of straw mushroom production.

1. Introduction

Risk management has emerged as a central issue in modern agriculture, where production processes are highly vulnerable to environmental fluctuations, biological contamination, and market uncertainty. Effective risk management frameworks are therefore crucial not only to ensure production efficiency but also to sustain long-term agricultural performance. Traditional approaches often focus on addressing individual risks in isolation, overlooking the systemic interactions that shape agricultural outcomes. This limitation has created the need for integrated models capable of identifying, prioritizing, and mitigating risks in a holistic manner.

In this context, the House of Risk (HOR) model represents an innovative methodological tool that extends beyond conventional Failure Mode and Effects Analysis (FMEA) and House of Quality (HOQ) frameworks. By quantifying risk events and correlating them with causal agents, HOR enables practitioners to determine priority risks and design proactive mitigation strategies (Anjalee et al., 2021; Pujawan & Geraldin, 2009). Recent studies have demonstrated its utility in supply chain management (Aini et al., 2019; Puji et al., 2019), yet its application in agriculture remains limited. Importantly, HOR offers scalability and adaptability across diverse commodities, from mushroom cultivation in tropical regions to large-scale production of wheat, rice, or horticultural crops worldwide. This adaptability underscores its potential as a globally replicable framework for agricultural risk management (Qazi & Akhtar, 2020).

Alongside methodological advances, the agricultural sector is undergoing a digital transformation through the adoption of smart farming technologies. Tools such as automated climate control and Internet of Things (IoT)-based monitoring systems provide real-time data that enhance decision-making and reduce human error (Guragain et al., 2024; Surige et al., 2021). Although digital agriculture has received increasing attention in global literature (Ferdousi et al., 2020; Khakhula et al., 2024), its integration with structured risk management models remains underexplored. This gap highlights the importance of combining digital solutions with robust risk analysis frameworks to strengthen resilience and competitiveness in agriculture, particularly in developing countries facing technological disparities (Hubay et al., 2024; Rukhiran et al., 2023).

Straw mushroom (Volvariella volvacea) is one of the popular types of mushrooms consumed as a processed food ingredient, commonly used in soups, vegetables, or stir-fries. This mushroom is known not only for its unique taste but also for its rich nutritional content, including high levels of protein, carbohydrates, and fiber, offering various health benefits (Kusmantini et al., 2022). In Indonesia, straw mushrooms account for 55-60% of the total national mushroom production, making it a key commodity in the agricultural sector. Most of the production is marketed in fresh form, especially to large cities, due to high domestic market demand (Melani, 2022).

Despite the growing market demand, the production of straw mushrooms in Indonesia experienced a significant decline in 2022. Data from the Central Statistics Agency (BPS) indicates that the total national mushroom production was recorded at 63.15 tons in 2022, representing a 30.15% decrease compared to the 90 tons produced in 2021 (Central Statistics Agency, 2023). The production decline highlights the imbalance between decreasing supply and increasing market demand. In addition to these factors, there are various risks in the production process of straw mushrooms that may impact the quality and output. According to Shah et al., (2021), risks that may arise during the production process include disruptions in the quality of raw materials, changes in weather conditions, or equipment malfunctions, all of which can lower production performance.

Therefore, it is crucial to analyze the application of risk management in the straw mushroom production process, focusing on the use of the House of Risk (HOR) model to identify, measure, and control the risks affecting the quality and outcome of production. This study aims to analyze the risks in straw mushroom production at Oemah Jamur using the HOR model, while also exploring the role of digital tools in mitigating priority risks. This study contributes to the advancement of sustainable and technology-driven agricultural practices by integrating methodological innovation with digital transformation.

Straw Mushroom Production

The production of straw mushrooms (Volvariella volvacea) has skyrocketed, particularly in tropical and subtropical countries such as Indonesia, Bangladesh, and India. This mushroom is known for its short cultivation period as well as its high nutritional content, including protein, fiber, and various vitamins such as vitamin C, making it a nutritious food source (Ali et al., 2024). In addition to its significant nutritional benefits, straw mushroom cultivation also has a major economic impact, especially in rural areas. According to Bisoyi et al., (2021), straw mushroom cultivation in rural areas provides employment opportunities with relatively low production costs. This creates job opportunities, particularly for women and smallholder farmers, while also contributing to food security and strengthening the local economy.

However, a key challenge in straw mushroom production lies in the selection of the appropriate substrate. Rice straw, which is abundant and affordable, serves as the primary substrate in this cultivation process (Thakur, 2020). Based on the research of Bermuli et al., (2022), rice straw has been identified as the optimal substrate due to its fiber content and nutritional profile that supports the biological efficiency of mushroom growth. Lestari et al., (2018) demonstrated that the choice of substrate significantly influences the quality and development of the mycelium, which can reach up to 8 cm in diameter. Singh et al., (2021) also indicated that the addition of other organic materials, such as poultry manure or other agricultural waste, can improve the carbon-to-nitrogen (C:N) ratio and enhance substrate quality, thereby supporting better straw mushroom production. The conversion of agricultural waste not only serves as mushroom substrate but also contributes to sustainability by creating a circular economy, where used mushroom substrates can be repurposed as fertilizer or animal feed, offering a solution for waste management and agricultural productivity enhancement (Baptista et al., 2023).

In addition to substrate factors, cultivation methods also play an essential role in production outcomes. The transition from an open system to indoor cultivation allows for better control of environmental factors such as temperature and humidity. However, it also faces challenges related to the need for adequate equipment and precise temperature control for optimal results (Ferdousi et al., 2020). Proper management of humidity and temperature has a significant impact on straw mushroom production. At the same time, the application of sustainable agricultural systems, such as vertical farming systems, improves space efficiency and reduces waste by recycling substrate into organic fertilizer after production (Ma et al., 2023).

Moreover, Faisal Radjab Munaward, (2017) showed that the average production yield of straw mushrooms reaches 200 kg per growing chamber measuring 6 m x 4 m x 4 m in one production cycle, using a growing medium consisting of rice straw, cotton, bran, and lime. The quality of the growing medium and the cultivation techniques applied greatly influence the success of production.

Risk Management in Straw Mushroom Production

In risk management, one of the key approaches is to identify potential risks and formulate strategies to manage them. In Fundamentals of Risk Management, Paul Hopkin (2017) states that risk management is the process of identifying, evaluating, and managing risks that could affect the achievement of an organization's objectives. One of the strategies applied in risk management is reducing the negative impacts of existing risks while also taking advantage of opportunities that may arise from such situations. The application of these strategies in straw mushroom cultivation can help farmers not only reduce losses but also maximize yields and optimize the sustainability of their businesses.

Volvariella volvacea (straw mushroom) grows optimally in a temperature range of 25–40°C, making it suitable for cultivation during both the dry and rainy seasons. However, from November to February, this mushroom struggles to grow under natural climatic conditions, where temperatures range from 23–27°C and relative humidity levels are between 55–65% (Mahapatra et al., 2020). Insufficient humidity can hinder mycelium growth, while optimal humidity has a positive effect on the protein content and other nutrients in the mushrooms (Asamoa et al., 2018). Therefore, an automated system is essential to monitor and control the appropriate climate conditions in real time to achieve optimal results (Guragain et al., 2024).

In addition to environmental factors, another risk to consider in straw mushroom cultivation is the presence of pathogens, such as Listeria monocytogenes, which are often found in humid production environments that are poorly maintained (Pennone et al., 2020). Li et al., (2023) & Das et al., (2024) highlight the threat of other pathogens, such as Serratia marcescens and Trichoderma spp., which can affect the quality and quantity of the mushrooms produced. Additionally, pests such as rodents, termites, and insects, as well as diseases such as damping-off and rot, can also reduce mushroom productivity (Okigbo, R N & Uwah, 2022). Thus, the implementation of integrated pest management and careful monitoring of pest populations during the cultivation process is crucial for maintaining the success of this enterprise (Pipaliya & Ansari, 2023).

Another challenge in mushroom cultivation is the limited availability of resources, such as labor and cultivation materials, which can hinder smooth agricultural operations and impact production outcomes (Hadush, 2020). Financial constraints, including costs related to substrate preparation, pest control, and overall farm management, also play a significant role in determining the feasibility and sustainability of mushroom farming operations. These factors affect the economic viability of smallholder farmers (S.M. Ayodele et al., 2024). Therefore, integrating sustainable practices, such as recycling agricultural residues into mushroom production, not only reduces waste but can also provide a cost-effective approach to substrate management (J. Singh, 2018).

House of Risk (HOR) Model in Risk Management

The House of Risk (HOR) model is a modification of the FMEA (Failure Mode and Effects Analysis), and HOQ (House of Quality) models used to assess, quantify, and prioritize risks, as well as select the most effective and efficient preventive actions while considering available resources (Pujawan & Geraldin, 2009). Essentially, FMEA is a systematic approach used to identify potential failures in a process, product, or service and to evaluate the impact of these failures. This allows organizations to prioritize risks based on their severity, likelihood of occurrence, and ease of detection (Anjalee et al., 2021; Borkovskaya, 2018). Meanwhile, HOQ serves as a tool for prioritizing risks and selecting the most effective mitigation actions (Hudy et al., 2023). Risk analysis can be performed through quantitative modeling, which can be adopted in the HOR model to strengthen decision-making based on data (Huang, 2020). In the context of selecting practical mitigation actions, the integration of FMEA and the HOQ model provides an added benefit by identifying priorities and relationships among risk elements. Puji et al., (2019) demonstrated that the combination of FMEA and HOQ methods offers a more comprehensive and accurate risk control analysis, providing a clear and in-depth understanding of various potential risks and applicable solutions in supply chain research.

Pareto Diagram

The Pareto diagram is an effective tool for identifying key activities that affect the outcome, thus helping in more precise decision-making (Sayout et al., 2020). Using the 80/20 principle, the Pareto diagram allows for the identification of the 20% of causes that may result in 80% of the risks, making the prioritization of risk management more efficient, as explained by Jean et al., (2024) in their research on zoonotic infections at the CIRMF Primate Center. Additionally, Gamberini et al., (2022) describe how the Pareto diagram is used to identify factors contributing to product losses, with the goal of enhancing the effectiveness of quality control systems in the industry. Haievskyi, (2020) also demonstrated that the Pareto diagram can be used to analyze defects in the production process, helping to prioritize areas for improvement by sorting defects based on the number detected.

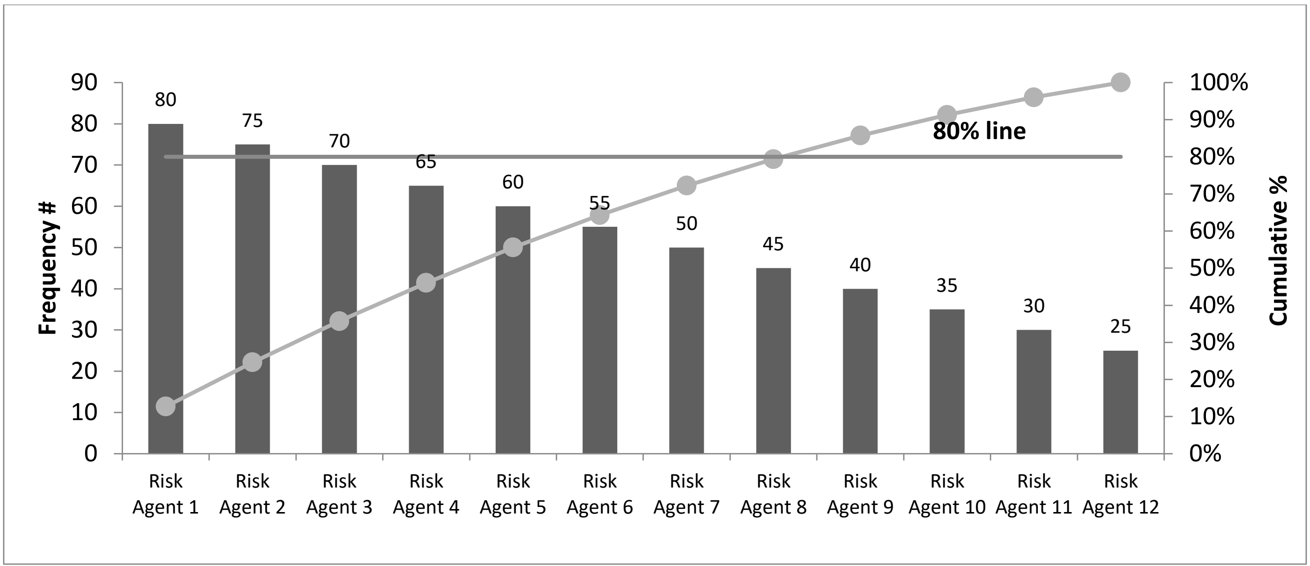

Figure 1. Pareto Diagram
Source: Data Processing Results

Risk Mitigation Strategies in Straw Mushroom Production

Risk mitigation strategies play a crucial role in ensuring the effectiveness and efficiency of the production process to enhance the production of straw mushrooms. Qazi et al., (2020) emphasize the importance of developing risk management tools that can address interdependent risks holistically rather than merely addressing risks separately to achieve efficient outcomes in the field. In this regard, Patil et al., (2024) highlight the importance of understanding the optimal conditions for the growth of various mushroom species, including managing environmental parameters to create a supportive microclimate, as well as utilizing advanced technologies to improve environmental control in mushroom cultivation.

Trang et al., (2023) explain that recognizing the optimal culture conditions can reduce the risk of contamination and increase harvest yields. Proper techniques can boost farmers' income by two to three times. An innovation-based approach to production risk management, which includes understanding disrupting factors, is also crucial. Hryvkivska et al., (2024) explain that effective risk management in agricultural enterprises requires a comprehensive assessment of existing risks and the development of appropriate mitigation measures.

The use of innovative tools in risk management is also an essential aspect of addressing threats in the production process. Khakhula et al., (2024) emphasize that both formal and informal tools are needed to tackle challenges in mushroom production. Furthermore, the selection of high-quality substrates has a significant impact on the quality of straw mushroom yields. Silva et al.,(2024) demonstrate that good cultivation practices, including substrate selection and pre-harvest processing, can improve the quality and durability of mushroom harvests.

On the other hand, using lignocellulosic waste as a substrate has the potential to reduce environmental pollution while providing economic and ecological benefits to the mushroom cultivation industry (Nath et al., 2024). This approach not only reduces fixed risks but also contributes to achieving sustainable development goals. Yasuhito Okuda, (2022) highlights that mitigating the negative impacts of mushroom production is vital to ensuring the long-term sustainability of the industry. By addressing the darker side of production, such as the environmental impact of mushroom waste, producers can implement more responsive strategies to these issues.

Facing these challenges, Pipaliya et al., (2023) note that mushroom farmers face various threats, including management, financial, and climate change issues, all of which require special attention for mitigation. In this context, the adoption of technologies, such as automated harvesting systems, can help reduce risks related to production efficiency and lower labor costs (Hubay et al., 2024).

2. Methods

This study adopts a mixed-methods approach by combining both qualitative and quantitative techniques to provide a comprehensive analysis of risks in straw mushroom production and the formulation of effective mitigation strategies at Oemah Jamur, Sleman, Yogyakarta. The qualitative component aims to capture the contextual and experiential dimensions of production risks, while the quantitative component is employed to measure and prioritize risks systematically through the House of Risk (HOR) model. This combination ensures that both subjective insights from practitioners and objective data analysis are integrated into the research process, thereby enhancing the robustness and reliability of the findings.

A case study approach was deliberately chosen to enable an in-depth exploration of the challenges specific to Oemah Jamur, a cultivation business managed under the Anwar Futuhiyyah Islamic Boarding School. By focusing on a single case, the study was able to provide nuanced insights into the production system, the unique risk exposures, and the contextual constraints of straw mushroom farming. This methodological choice is aligned with the study's objective to not only identify risks but also to understand how they manifest within the operational and organizational realities of the enterprise.

The primary data collection involved several strategies. First, in-depth interviews were conducted with the production manager and key workers directly involved in different stages of the production cycle—preparation, inoculation and incubation, and harvesting. The interviews sought to elicit detailed information regarding the sources of risks, their perceived impacts, and the mitigation strategies that had been attempted. Second, direct field observations were carried out to complement the interview data by capturing daily practices, environmental conditions, and operational challenges that might not be explicitly mentioned by the respondents. Third, secondary data such as production records, weather reports, and documentation of previous risk events were reviewed to triangulate the information obtained from interviews and observations. This triangulation process enhances the validity and reliability of the research outcomes by ensuring that findings are not reliant on a single source of evidence.

The House of Risk (HOR) model serves as the central analytical framework for the quantitative part of the study. The application of HOR was conducted in two distinct phases. In Phase I, the study identified risk events (E) and their corresponding risk agents (A). Each risk event was assigned a severity score on a scale of 1–10, while each risk agent was evaluated based on its frequency of occurrence. The Aggregate Risk Potential (ARP) was then calculated by multiplying the severity, occurrence, and correlation scores. This enabled the identification of risk agents that contributed most significantly to overall risk exposure. In Phase II, mitigation actions were formulated and evaluated by considering both their effectiveness in addressing multiple risks and their degree of implementation difficulty. The calculation of Effectiveness-to-Difficulty Ratio (ETDk) provided a prioritization of mitigation strategies, with actions such as the implementation of an automatic climate control system, standardized pasteurization processes, and improved ventilation emerging as top priorities.

To ensure data validity and reliability, a triangulation strategy was systematically employed. Data derived from interviews were cross-checked with field observations and compared with secondary data to identify consistencies and discrepancies. The qualitative data from interviews were analyzed using thematic analysis, allowing the identification of recurring themes related to risk sources, impacts, and coping strategies. Meanwhile, the quantitative results from the HOR analysis were summarized using descriptive statistics and visualized through Pareto diagrams to highlight priority risks and their relative contributions.

This methodological design enables a comprehensive understanding of risk dynamics in straw mushroom production. The integration of qualitative narratives with quantitative risk assessment ensures that the analysis captures both the lived experiences of practitioners and the structured prioritization of risk sources. By employing a case study framework, triangulated data collection, and the HOR model, this study provides a rigorous foundation for developing effective and contextually relevant risk mitigation strategies in agricultural enterprises like Oemah Jamur.

3. Results

Oemah Jamur is a business engaged in the production of straw mushrooms, founded in 2021 by Badan Usaha Milik Pesantren (BUMP) Anwar Futuhiyyah in Sleman, Yogyakarta. To identify and manage the risks in the straw mushroom production process at Oemah Jamur, a risk analysis was conducted using the House of Risk (HOR) method, which has been proven effective. This method combines the Failure Mode and Effects Analysis (FMEA) model, modified to measure risks quantitatively, and the House of Quality (HOQ) model to identify the risk agents that should be prioritized for mitigation. With this approach, Oemah Jamur can determine the most effective actions to reduce potential risks arising from these risk agents.

Risk Event Identification

The identification results revealed that 13 risk events were coded (E1-E13). These risk events can be grouped into 3 stages of straw mushroom production: preparation, inoculation and incubation, and harvesting. Each identified risk event has a severity level measured on a scale of 1 to 10, where the higher the scale, the more severe the risk event is. Table 1 is the risk identification table containing details of the risk events along with their severity levels at Oemah Jamur.

Table 1. Risk Events and Severity Levels

Stage	Risk Event	Code	Severity Level
Production preparation	Market price fluctuations or high operational costs	E1	7
Inoculation and incubation	Uneven mycelium growth or no growth	E2	9
	Infection by pathogens such as Trichoderma or Fusarium	E3	9
	Uneven distribution of light in the cultivation house	E4	8
	Fluctuations in environmental humidity that are not ideal	E5	8
	Fluctuations in temperature in the cultivation room (house) that are not optimal	E6	8
	Mushrooms fail to grow or grow suboptimally	E7	9
	Inadequate monitoring of temperature, humidity, and light	E8	8
	Emergence of competing fungi such as Mucor or Rhizopus	E9	8
	Damage to the growing medium and the mushrooms	E10	8
	Several small mushrooms die before fully growing	E11	9
Harvest	Decreased mushroom yield	E12	9
	Decreased mushroom quality	E13	9

Source: Based on Data Primer Processing

Risk Agent Identification

A total of 13 distinct risk events have been identified in the straw mushroom production process, each of which can be traced back to 16 different risk sources, commonly referred to as risk agents. These risk agents, coded systematically from A1 to A16, represent various factors that have the potential to trigger one or more risk events during cultivation, incubation, or harvesting. For instance, pathogens, poor-quality raw materials, and unstable environmental conditions are among the most frequent contributors to production risks. To evaluate the likelihood of these risk agents, each was assessed using an occurrence scale ranging from 1 to 10. On this scale, a higher value signifies a greater probability of occurrence, thereby highlighting which agents require urgent attention. The results of this assessment are summarized in Table 2, which presents the identified risk sources along with their potential occurrence levels at Oemah Jamur, serving as the foundation for subsequent HOR analysis.

Table 2. Risk Sources and Potential Causes (Occurrence)

Code	Risk Source (Risk Agent)	Occurrence (Potential Cause)
A1	Microorganisms, pathogenic fungi, bacteria	9
A2	Low-quality mushroom spawn	9
A3	Dependence on specific raw materials	8
A4	Uneven inoculation technique	9
A5	Poorly maintained incubation room or mushroom house	9
A6	Unstable fluctuations in temperature, humidity, and lighting	9
A7	Malfunctioning ventilation system	8
A8	Unstable pasteurization process or failure to meet targets	9
A9	Pests such as insects, caterpillars, mites, and rodents	8
A10	Non-sterile or insufficient raw materials for the medium	9
A11	Dependence on part-time labor	7
A12	Extreme weather conditions (heat, heavy rain)	8
A13	Malfunctioning temperature, humidity, and lighting control systems	8
A14	Excessive or insufficient moisture in the medium	9
A15	Delayed mushroom harvesting or harvesting too early	7
A16	Poorly sealed cloth or tarp covering the mushroom house	7

Source: Based on Data Primer Processing

Determining Priority Risk Sources

A Pareto diagram is used to determine the priority risk sources. This diagram illustrates the risk sources that should be prioritized. The priority risk sources are obtained from the Aggregate Risk Potential (ARP). The ARP value is calculated by multiplying the severity, occurrence, and correlation values (between the risk event and the risk source).

$$For\ example, ARPI = (8)x\{(9x7) + (3x9) + (9x9) + (9x9)\}$$

Explanation: The number 8 represents the occurrence value, which indicates how often a particular risk source is expected to appear during the production process. The numbers 1, 3, and 9 are the correlation values that illustrate the degree of association between a risk event and its respective risk source, with higher values showing stronger relationships. Meanwhile, the numbers 7 and 9 denote the severity values, reflecting the magnitude of the potential consequences if the risk event occurs. By multiplying the severity, occurrence, and correlation values, the Aggregate Risk Potential (ARP) for each risk source can be systematically calculated. To determine the cumulative ARP, the individual ARP values are summed. For example, the ARP of risk source A6, which equals 7.614, when added to the ARP of risk source A5, which is 6.552, results in a cumulative total of 14.166, as shown in Table 3. With a total ARP value of 69.144, the ARP percentage is obtained by dividing each risk source's ARP by this total, enabling prioritization of the most critical risks.

Table 3. Cumulative ARP Values

Ranking	Risk Agent	ARP	Cumulative ARP	% ARP	% Cumulative ARP	Category
1	A6	7.614	7.614	11%	11%	Priority
2	A5	6.552	14.166	9%	20%	Priority
3	A14	6.552	20.718	9%	30%	Priority
4	A1	5.904	26.622	9%	39%	Priority
5	A4	5.238	31.860	8%	46%	Priority
6	A13	5.112	36.972	7%	53%	Priority
7	A2	4.293	41.265	6%	60%	Priority
8	A10	4.293	45.558	6%	66%	Priority
9	A8	4.239	49.797	6%	72%	Priority
10	A12	4.200	53.997	6%	78%	Priority
11	A7	4.129	58.126	6%	84%	Non Priority
12	A9	3.984	62.110	6%	90%	Non Priority
13	A3	2.232	64.342	3%	93%	Non Priority
14	A16	2.163	66.505	3%	96%	Non Priority
15	A11	1.673	68.178	2%	99%	Non Priority
16	A15	966	69.144	1%	100%	Non Priority

Source: Based on Data Primer Processing

An example of the calculation for the risk source A6, with an ARP value of 7,614 divided by 69,144, results in an ARP percentage of 11%.

Next, to calculate the cumulative ARP percentage, the cumulative ARP value of each risk source is divided by the total ARP. For example, for risk source A5 with a cumulative ARP value of 14.166, dividing by 69.144 results in a percentage of 20%. The subsequent calculations use the Pareto diagram, which illustrates that 80% of losses are caused by 20% of the most significant risks. By focusing on 20% of the most critical risks, approximately 80% of the risk impact can be minimized.

The identification results show that there are 10 priority risk sources. The determination of priority risk sources is based on the cumulative ARP percentage. If the cumulative ARP percentage of a risk source falls within 80%, it is categorized as a priority. Fluctuations in temperature, humidity, and lighting instability (A6) are the highest, with an ARP value of 7.614. This indicates that this risk source has a significant impact on the production of straw mushrooms at Oemah Jamur. Temperature, humidity, and lighting fluctuations in the straw mushroom production process are considered the top priority because they have been the main challenges for the company in mushroom production.

Based on Reddy et al., (2022), fluctuations in temperature, humidity, and light intensity are significant factors affecting the success of straw mushroom cultivation. This research identified that higher temperatures and lower humidity, especially in broader planting distances without mulching, can create unfavorable conditions for mushroom growth. This condition increases the risk of production failure due to its negative impact on growth stages like mycelium elongation and fruit body formation.

The Pareto diagram (Figure 2) illustrates the priority risk mitigation actions. Based on the diagram, 10 risk sources are prioritized. In the Pareto diagram, the risk sources are located on the horizontal axis, while the vertical axis shows the cumulative ARP percentage. The company can focus on these 10 risk sources, which will then be considered in formulating the risk mitigation actions during the second phase of HOR.

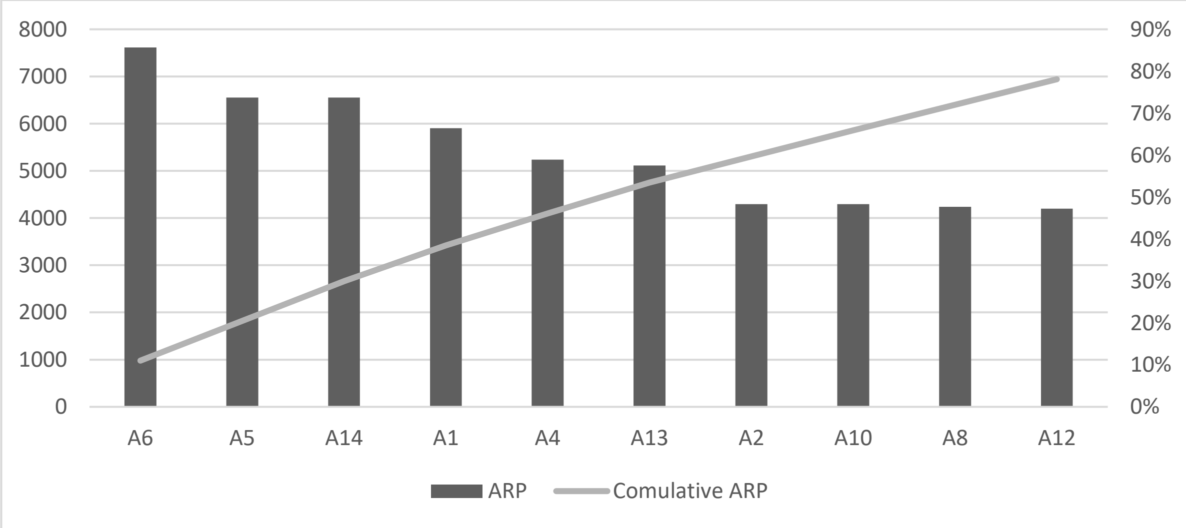

Figure 2. Pareto Diagram of Risk Agents in Straw Mushroom Cultivation
Source: Data Processing Results

Determining Mitigation Actions

In this stage, risk management strategies are designed to address the priority risk sources. Priority mitigation actions are applied to minimize as many risks as possible before implementing mitigation actions. Table 4 presents the calculation of total effectiveness (TEk), which is computed by multiplying the correlation value (between risk sources and mitigation actions) by the ARP value. The degree of difficulty (Dk) is determined by the company, assigning values of 3, 4, or 5, with criteria: 3 (easy to implement), 4 (somewhat tricky to implement), and 5 (difficult to implement). The effectiveness to difficulty ratio (ETDk) is then calculated by dividing the total effectiveness (TEk) by the degree of difficulty (Dk). Based on the efficacy to difficulty ratio (ETDk) calculations, it was found that the mitigation action of implementing an automatic climate control system (PA4) is the top priority, with the highest ETDk value of 102.775. This mitigation action is prioritized because it can minimize risks during the incubation phase, such as monitoring fluctuations in temperature, humidity, and light intensity.

Table 4. House of Risk Stage 2 Table

Ranking	Code	Mitigation Action	TEk	Dk	ETDk
1	PA4	Implementation of an automatic climate control system	308.325	3	102.775
2	PA6	Standardization of the pasteurization process by ensuring that temperature and time are by procedures	286.599	3	95.533
3	PA5	Improvement of the ventilation system to ensure proper air circulation	264.789	3	88.263
4	PA3	Regular maintenance and monitoring of the incubation room to ensure cleanliness and proper room conditions	348.669	4	87.175
5	PA8	Proper management of media humidity	312.714	4	78.179
6	PA2	Proper inoculation techniques according to procedures	230.997	4	57.749
7	PA1	Use of high-quality tested mushroom spawn	156.067	3	52.022
8	PA7	Enhanced supervision and sterilization of media raw material	124.065	4	31.016

Source: Based on Data Primer Processing

The following prioritized mitigation action is integrated pest and disease management (PA6) with an ETDk value of 95.533. This mitigation action is prioritized because the company needs to implement standardization of the pasteurization process by ensuring that temperature and time are consistent with the procedures. The subsequent priority mitigation action is the implementation of a staggered harvest planning system (PA3) with an ETDk value of 88.263. This action is prioritized because enhancing the ventilation system ensures proper air circulation, which is essential for supporting optimal mushroom growth. To support the implementation of these mitigations, an Internet of Things (IoT)- based monitoring system allows for real-time adjustments of cultivation parameters such as temperature, humidity, and light, ensuring optimal conditions to enhance mushroom growth Rukhiran et al., 2023).

4. Discussion

The findings of this study reveal the importance of adopting a structured risk management approach in straw mushroom cultivation. Using the House of Risk (HOR) model, the analysis identified temperature, humidity, and lighting fluctuations as the most significant sources of risk. These microclimate factors directly affect the growth of mycelium and the formation of fruiting bodies. Prior studies confirm that environmental instability is a major cause of yield reduction in mushroom production (Reddy et al., 2022). Thus, ensuring consistent environmental management is critical for achieving stable and sustainable production outcomes.

Technological interventions emerged as central solutions to mitigate these risks. The adoption of an automatic climate control system was prioritized as the most effective action, offering precise management of environmental parameters. When integrated with Internet of Things (IoT) technology, this system provides real-time monitoring and reduces the possibility of human error (Guragain et al., 2024; Rukhiran et al., 2023). Such integration allows quick adjustments to production conditions, creating a more resilient and responsive farming system. In turn, these digital tools enhance the overall efficiency and reliability of mushroom cultivation.

Complementary strategies were also identified to strengthen production processes. Standardizing pasteurization, improving ventilation, and sterilizing raw materials were found to be effective in reducing contamination risks. Pathogens such as Trichoderma spp. and Fusarium are common threats that can significantly decrease production yield and quality (Das et al., 2024; Li et al., 2023). Preventive sanitation and proper airflow circulation address these challenges while maintaining the health of the growing environment. Together, these measures contribute to a more comprehensive and systematic approach to risk management in mushroom production.

Economic considerations add another dimension to the findings. For small-scale enterprises such as Oemah Jamur, limited financial and human resources pose challenges to adopting advanced technologies. The HOR framework assists in prioritizing mitigation actions by comparing their effectiveness with implementation difficulty. Although installing automated systems requires significant investment, the long-term benefits in reducing multiple risks justify the cost. This reinforces the principle of efficiency and resource optimization for sustaining smallholder agribusinesses.

Sustainability practices also emerged as an important element of risk reduction. The use of agricultural waste as a mushroom substrate demonstrates how risk management can align with ecological objectives. Recycling straw and other residues supports a circular economy while lowering production costs (Baptista et al., 2023). When combined with improved environmental controls, this practice enhances both economic resilience and environmental responsibility. Therefore, risk mitigation strategies extend beyond immediate production concerns and contribute to broader sustainability goals.

Finally, the study highlights the value of combining traditional farming knowledge with digital innovations. Farmers bring contextual understanding of local risks, while modern tools add precision and consistency to mitigation strategies. The HOR model provides a bridge, integrating both perspectives into a unified framework for decision-making. This dual approach not only improves production outcomes but also strengthens long-term adaptability. As a result, Oemah Jamur can position itself as a model for risk-aware, technology-driven, and sustainable mushroom farming in Indonesia.

5. Conclusions

This study explores risk management in producing straw mushrooms at Oemah Jamur, using the House of Risk (HOR) model to identify and assess the existing risks. The findings reveal several risk factors that can impact the smoothness and quality of straw mushroom production. These risks include price fluctuations, low-quality seeds, pathogen infestations, and extreme climate changes. Identifying risk events uncovered 13 factors that potentially hinder production, each with varying levels of severity. Through implementation of the HOR model, priority risk sources were successfully identified using Aggregate Risk Potential (ARP), which links risk events with their causal agents. Unstable temperature, humidity, and lighting were the most significant risk factors, severely impacting mushroom growth's incubation stage. Therefore, mitigation efforts should focus on the automatic climate control system, improved ventilation systems, and ensuring the cleanliness of the incubation space.

The proposed mitigation strategies include implementing an automatic climate control system, standardizing the pasteurization process, and enhancing the maintenance of incubation rooms. These prioritized mitigation actions aim to reduce the main risks disrupting straw mushroom production and improve overall product quality. Furthermore, an IoT-based monitoring system can offer an innovative solution for real-time environmental control, supporting production efficiency and effectiveness. This study provide significant contributions to understanding the application of the House of Risk model for risk mitigation in straw mushroom production while offering practical steps to enhance the sustainability and quality of production in the agricultural industry, particularly in the cultivation of straw mushrooms in Indonesia.

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