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Simulation and Analysis of Production Risk Using Fuzzy Computation and FMEA Method in MATLAB

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ABSTRACT

This study applies the Fuzzy Failure Mode and Effects Analysis (Fuzzy FMEA) method to identify, evaluate, and prioritize potential failures in the rice milling production process at Mas Nun's facility. A total of 14 failure modes were identified based on primary data collected through direct observation, interviews, and literature review. The traditional Risk Priority Number (RPN) was calculated using severity, occurrence, and detection scores, and then refined through fuzzy logic modeling implemented in MATLAB R2022a using the Mamdani inference method. The results show that machine malfunction represents the highest risk with an RPN of 567 and a Fuzzy Risk Priority Number (FRPN) of 827. Additional high-priority failures include high moisture content in rice, poor grain quality, and inadequate drying processes. The fuzzy approach significantly enhances risk prioritization by handling linguistic uncertainty and producing more nuanced FRPN rankings. The study also integrates the 5W+1H framework to propose structured preventive and corrective actions. These findings underscore the relevance of Fuzzy FMEA in agro-industrial settings, particularly for small and medium enterprises (SMEs), by enabling more accurate risk assessment and improving production quality control.

Keywords: Fuzzy FMEA, Risk Assessment, Rice Milling, Fuzzy Logic, MATLAB

INTRODUCTION

The rice milling industry plays a strategic role in supporting food security and economic sustainability in Indonesia. As the primary staple food, rice quality directly influences consumer trust and market competitiveness. However, defects in the production process—such as yellowing rice, broken grains, dirty rice, and unhusked paddy—remain common problems in small and medium-sized rice mills. These issues are not only technical but also managerial, as they relate to machinery performance, drying methods, and quality control practices. Without effective risk management, such failures can lead to financial losses and declining customer confidence.

The main problems in rice milling are the high number of defects in the form of broken rice (411 kg/year), yellow rice (379 kg/year), dirty rice (221 kg/year), and unhusked grain (18 kg/year), even though production volume is relatively stable. The high number of broken rice grains, especially in November (55 kg) and February (65 kg), indicates weaknesses in the drying process and the performance of the milling machine, while the peak of yellow rice in January-February indicates weak storage management and moisture control during the rainy season. The consistent defect of dirty rice every month shows problems with production area cleanliness and contamination control, while the presence of unhusked grain reflects the inefficiency of the husking process. The accumulation of these problems confirms weak quality control at every stage of production (input, process, to output), which has the potential to reduce product quality, reduce consumer confidence, and cause financial losses for business actors.

Several previous studies have examined the application of Failure Mode and Effects Analysis (FMEA) to evaluate risks in agroindustry. Conventional FMEA, while systematic, often faces limitations in dealing with linguistic uncertainty and subjectivity in determining severity, occurrence, and detection values [1]. This results in inconsistent Risk Priority Number (RPN) rankings and difficulties in prioritizing corrective actions. Therefore, integrating computational methods such as fuzzy logic is necessary to refine traditional FMEA results and provide more accurate risk assessments [2].

The research gap identified is that most studies on risk management in rice milling and related agro-industries still rely on conventional FMEA. Very few have explored the Fuzzy FMEA approach combined with simulation tools such as MATLAB in small and medium enterprises (SMEs). Furthermore, existing works often stop at identifying risks without providing structured improvement strategies that can be directly applied by practitioners. This gap highlights the need for a more comprehensive model that not only identifies and ranks risks but also supports decision-making for corrective actions.

The novelty of this research lies in the application of Fuzzy FMEA integrated with MATLAB Mamdani inference to analyze rice milling production failures systematically. By employing fuzzy computation, the study reduces subjectivity in evaluating risk factors, thus producing a more nuanced Fuzzy Risk Priority Number (FRPN) compared to traditional RPN. In addition, this study strengthens the practical contribution by combining risk prioritization with the 5W+1H framework, providing SMEs with structured guidance for preventive and corrective measures.

The main problems addressed in this study are the high frequency of rice defects and machinery failures in the production process at Mas Nun's rice mill, which negatively affect rice quality and consumer trust [3], [4]. Specifically, the study investigates the causes and prioritization of potential failures across raw materials, production processes, and final product stages. The inadequacy of conventional risk analysis methods in capturing uncertainty further motivates the use of a fuzzy-based approach [5], [6].

Accordingly, the objective of this research is to apply the Fuzzy FMEA method to identify, analyze, and prioritize potential failures in rice milling production [7]. The study also aims to compare the results of conventional RPN and fuzzy-based FRPN calculations to demonstrate the added value of fuzzy logic in risk analysis. Finally, by integrating the 5W+1H framework, this research provides practical recommendations for SMEs in the agro-industrial sector to enhance quality control, minimize production risks, and improve consumer satisfaction [8].

METHOD

This research began with a preliminary study and literature review to identify the main problems in the rice milling production process [9]. The next stage was data collection, including primary data through interviews, direct observation, and secondary data in the form of company data and previous research [10]. Once the problems were defined, an analysis was conducted using the Failure Mode and Effects Analysis (FMEA) method by assessing the severity, occurrence, and detection capability of each failure mode, which was then calculated into a Risk Priority Number (RPN) [11]. To overcome the limitations of conventional FMEA in dealing with linguistic uncertainty, this study continued with the application of Fuzzy FMEA. At this stage, the input variables (Si, Oi, Di) were fuzzified, fuzzy rules were formulated, and defuzzification was performed to produce a more accurate Fuzzy Risk Priority Number (FRPN) [12]. The RPN and FRPN results are then analyzed to compare risk priorities and determine critical failures that must be addressed immediately. The final stage consists of analysis, conclusion drawing, and the preparation of improvement recommendations based on 5W+1H as a strategy for prevention and continuous improvement [13].

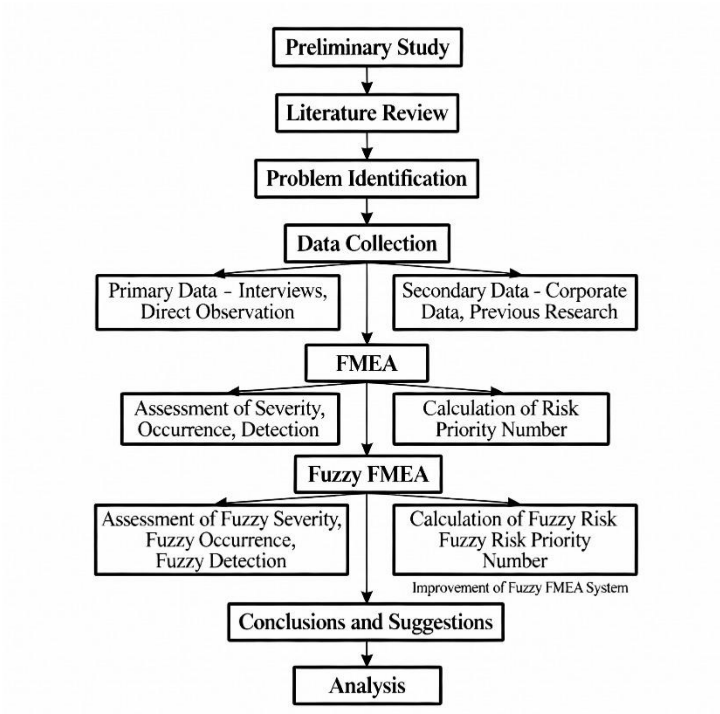


Figure 1. Research Stages

The initial steps involve data collection through observation, literature review, and interviews. Interviews consist of direct question-and-answer sessions with sources related to the data used in this research [14]. The primary data source for this study is the owner of the rice production business. The collected data includes factors causing rice defects and types of imperfections in the rice. Once the data is gathered, it is processed using the Fuzzy method and FMEA [15].

A. FMEA

Failure Mode and Effect Analysis (FMEA) is an engineering technique used to establish, identify, and prevent known failures, problems, errors, and similar issues in a system, design, process, and service before they reach the customer or consumer [16].

RPN (Risk Priority Number) is a mathematical product of the severity of the effect, the likelihood of occurrence of a failure related to the effect, and the ability to detect the failure before it reaches the customer [17].

B. Fuzzy FMEA

Fuzzy processing is performed using MATLAB R2022a software. The fuzzy input includes values for severity, occurrence, and detection. After completing the fuzzification stage, the next step is to apply the fuzzy if-then rules (fuzzy rule base) [18]. The final stage of fuzzy FMEA involves defuzzification to determine the FRPN value. The method used for defuzzification is the Centroid (Composite Moment) method, which calculates the centroid of the fuzzy set to obtain the crisp solution [19].

RESULTS

This study employs the Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA) method to systematically evaluate potential failure modes in rice quality. The application of Fuzzy FMEA enables the integration of fuzzy logic into conventional FMEA, thereby minimizing subjectivity in the assessment of risk factors such as severity, occurrence, and detection. The outputs of this method consist of the traditional Risk Priority Number (RPN) and the enhanced Fuzzy Risk Priority Number (FRPN), both of which are used to determine the priority level of each defect.

In this research, 14 types of rice defects were identified and analyzed using the Fuzzy FMEA framework. The structured procedure involves the following stages: (1) identification of potential defects and their associated failure modes, (2) assignment of linguistic values for severity, occurrence, and detection, (3) fuzzification of these linguistic assessments, (4) computation of FRPN values using fuzzy inference, and (5) ranking of defects based on both RPN and FRPN results.

FMEA, as a reliability and risk assessment tool, provides a systematic approach to detect, analyze, and prioritize potential failures before they occur. By generating numerical priority indices, FMEA helps decision-makers identify critical defects that require immediate corrective measures. In this study, the comparison between RPN and FRPN rankings highlights the added precision and reduced ambiguity achieved through fuzzy logic integration.

Table 1. Identify Failure Models

Process Stage	Potential Failure Mode	Potential Effect(s) of Failure	Potential Cause(s) of Failure	Existing Control Measures
Raw Material Handling	Prolonged storage of paddy	Deterioration of grain quality due to mold growth and microbial contamination	Extended storage duration under inadequate environmental conditions	Implementation of controlled storage systems and periodic monitoring

Process Stage	Potential Failure Mode	Potential Effect(s) of Failure	Potential Cause(s) of Failure	Existing Control Measures
Raw Material Handling	Mixing of paddy with other crop types	Reduction in consistency of grain quality	Lack of effective sorting and quality control mechanisms	Segregation of paddy batches and quality inspection prior to processing
Production Process	Inadequate drying	High moisture content leading to poor grain quality and reduced shelf-life	Unfavorable weather conditions; insufficient drying procedures	Utilization of mechanical dryers with controlled air flow and temperature
Production Process	Machinery malfunction	Wastage of raw material and reduced process efficiency	Lack of routine maintenance and mechanical defects	Scheduled preventive maintenance and operator training
Finished Product	Yellowed rice	Reduction in consumer acceptability and market value	Extended storage of high-moisture rice	Monitoring of moisture content and optimization of storage conditions

The final step in the FMEA method is to calculate the Risk Priority Number (RPN). As noted by Gasperz, this value is the product of the severity, occurrence, and detection ratings [16]. The RPN determines the priority of failures. After obtaining the severity, occurrence, and detection values, the RPN is calculated by multiplying these values together. The results are then ranked from highest to lowest RPN.

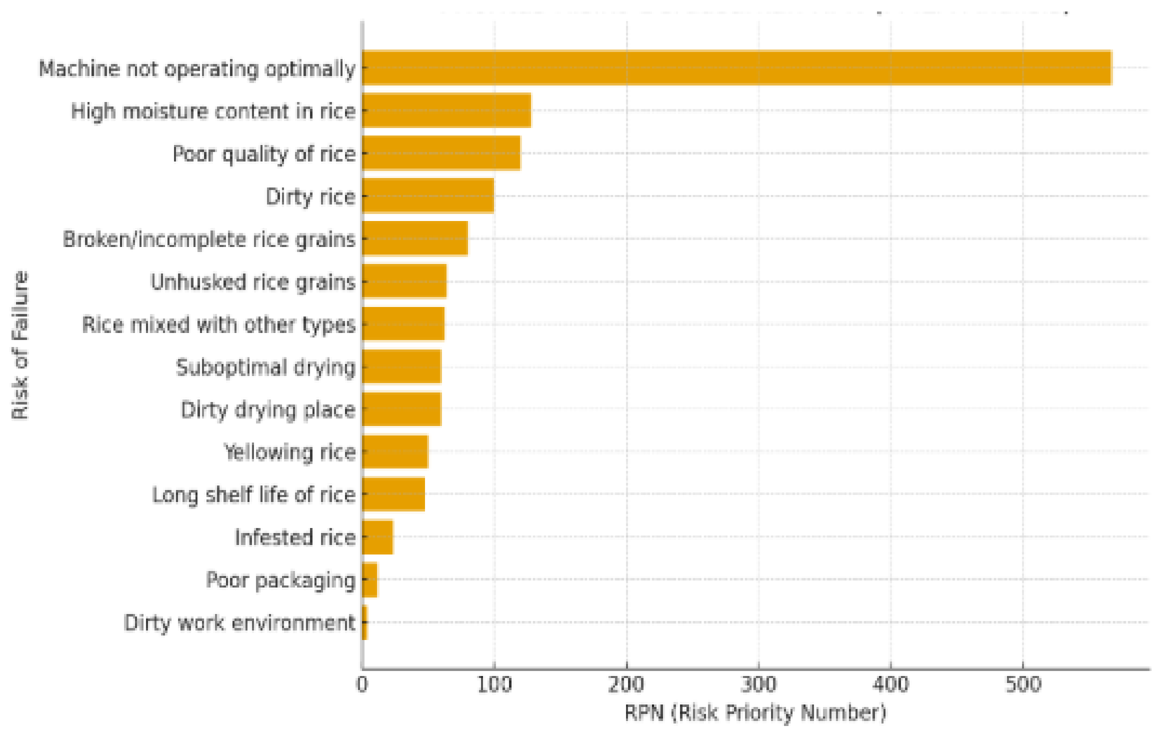


Figure 2. RPN of Rice Milling Production

Based on the FMEA analysis results, the failure risk with the highest RPN value is the machine not operating optimally (RPN 567), making it the top priority for improvement. Other factors that also have high RPN values are high moisture content in rice (RPN 128) and poor rice quality (RPN 120), which have the potential to affect the quality of the final product. Meanwhile, risks with low RPNs, such as a dirty work environment (RPN 4), indicate a relatively low priority for improvement.

A. Fuzzy FMEA

The Risk Priority Number (RPN) values derived from the FMEA calculations are subsequently analyzed using fuzzy logic in order to increase the robustness and reliability of the results. The procedure for processing data with fuzzy FMEA is outlined as follows

• Fuzzy If-than

The fuzzy-if-then process is carried out by following steps such as clicking the "Edit" menu and then selecting "Rules." In fuzzy-if-then logic, if a specific input value is present, it will yield a corresponding output value. In this case, there are three input variables: severity, occurrence, and detection, each with five categories. As a result, the total number of rules generated is 125. Each rule connects combinations of values from the three input variables (5 categories × 5 categories × 5 categories = 125 combinations) with the corresponding output values based on the predefined fuzzy logic using the Mamdani method and the previously created membership curves. The following are the rules generated in the fuzzy-if- then system:

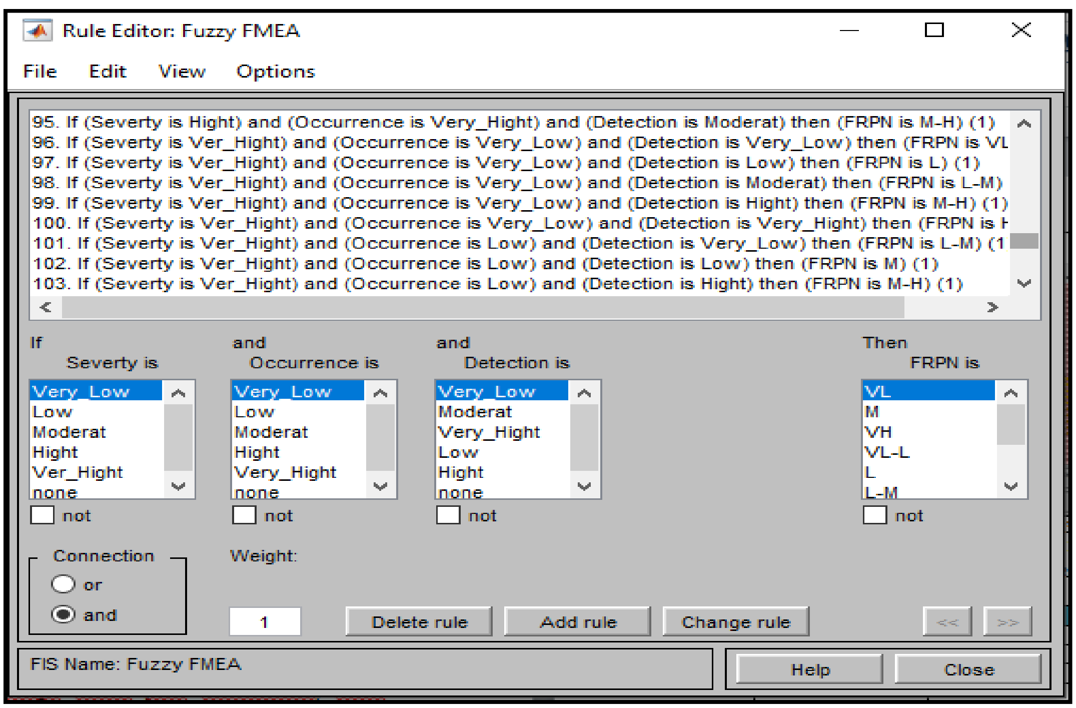


Figure 3. Fuzzy If-than

• Defuzzification

After the rules are generated as part of the defuzzification process, the fuzzy FMEA experiment can be conducted by selecting the "View" menu and then choosing "View Rules," which displays the fuzzy FMEA trial graph. Next, input the values for severity, occurrence, and detection (SOD), and the defuzzification results, which represent the FRPN values, will be displayed.

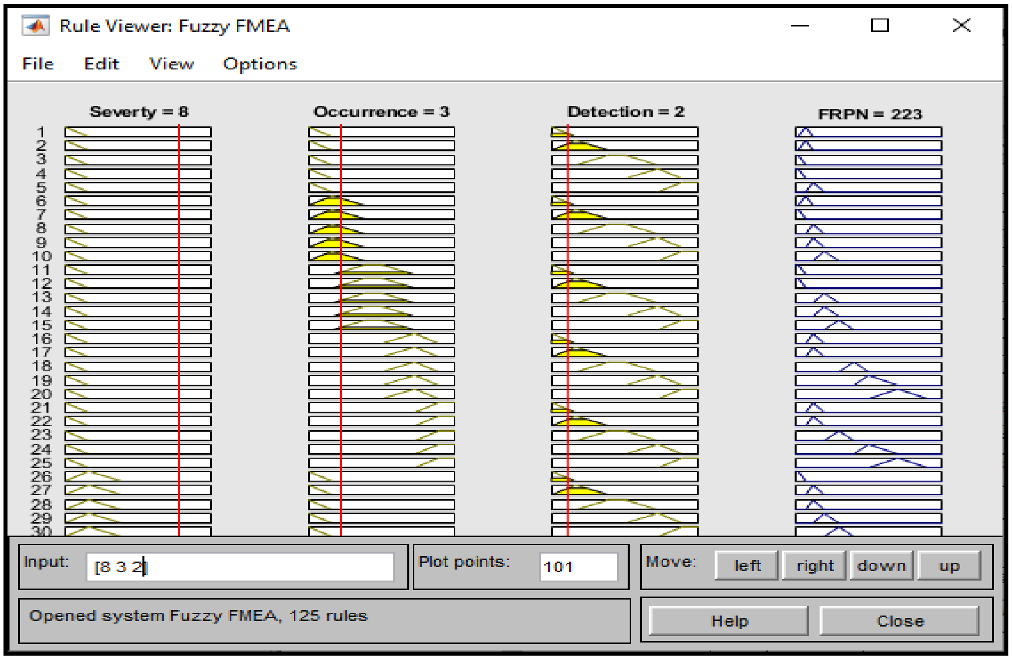


Figure 4. Defuzzification

Rule Viewer interface from the fuzzy logic-based Failure Mode and Effects Analysis (Fuzzy FMEA) system, implemented using the MATLAB Fuzzy Logic Toolbox. The input parameters include Severity (S) = 8, Occurrence (O) = 3, and Detection (D) = 2. These crisp values are fuzzified through predefined membership functions, activating a subset of the 125 fuzzy inference rules defined within the system.

As shown in the figure, the vertical red lines within each input variable column represent the degree of activation for each fuzzy membership function. The yellow shaded regions indicate the fired rules corresponding to the given input combination. The fuzzy inference engine aggregates the outputs from all active rules and defuzzifies the result using the centroid method, yielding a Fuzzy Risk Priority Number (FRPN) of 223.

Unlike the conventional RPN approach, where the risk priority number is calculated as a direct product of S, O, and D (i.e., RPN = S × O × D = 8 × 3 × 2 = 48), the fuzzy logic-based approach enables more nuanced risk assessment. This method accounts for linguistic uncertainties and expert judgment embedded in the rule base, resulting in a more flexible and realistic prioritization of potential failures. The elevated FRPN value of 223 indicates a higher perceived risk level when uncertainty and vagueness in assessment are properly modeled.

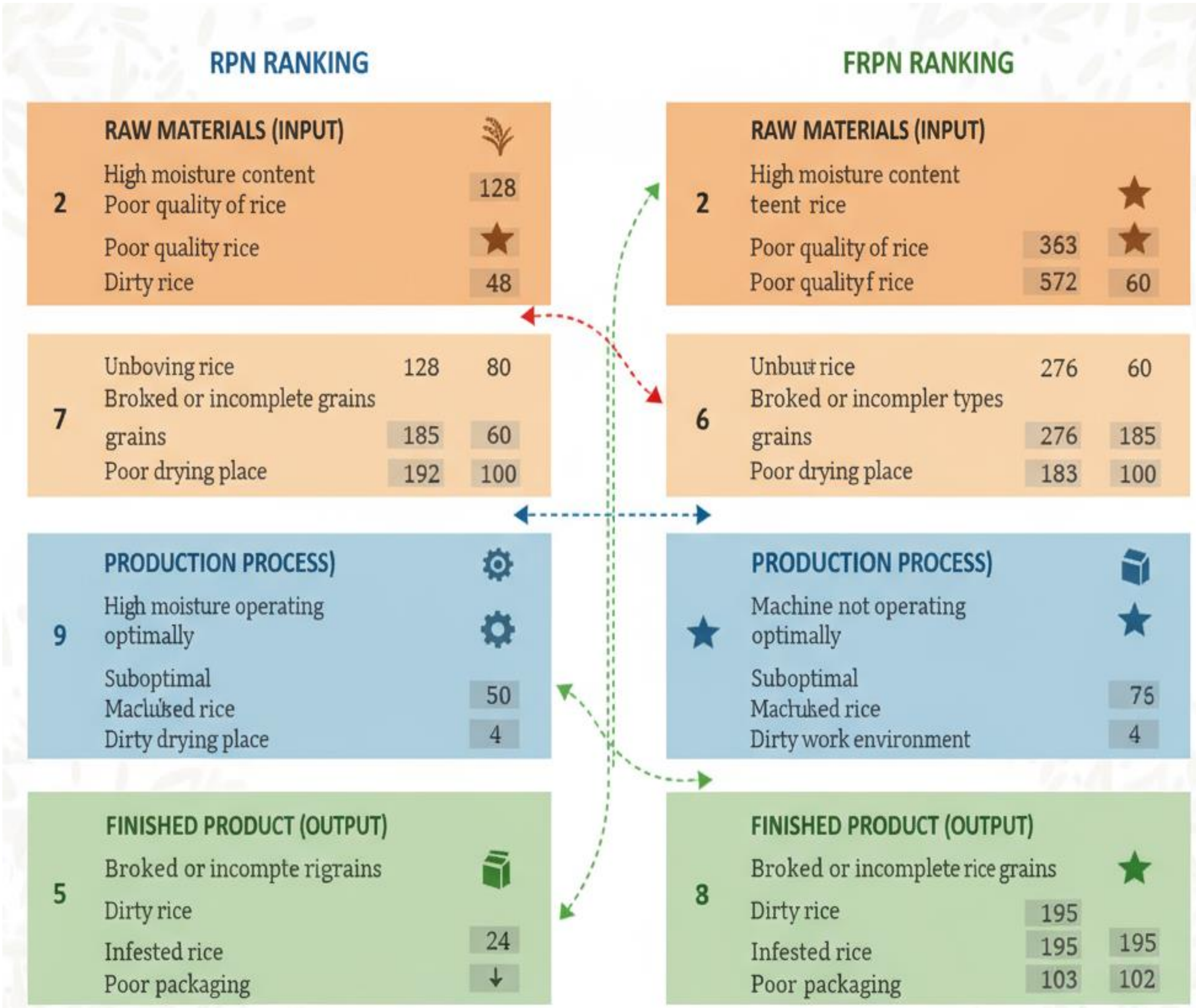


Figure 5. Priorities for rice management

Among the raw material risks, "High moisture content in rice" registers a significantly high RPN of 128 and is ranked second, highlighting the critical need for moisture control during harvesting and storage. Another prominent raw material risk is the "Poor quality of rice," with an RPN of 120 and ranked third, indicating the essentiality of quality monitoring from the input stage.

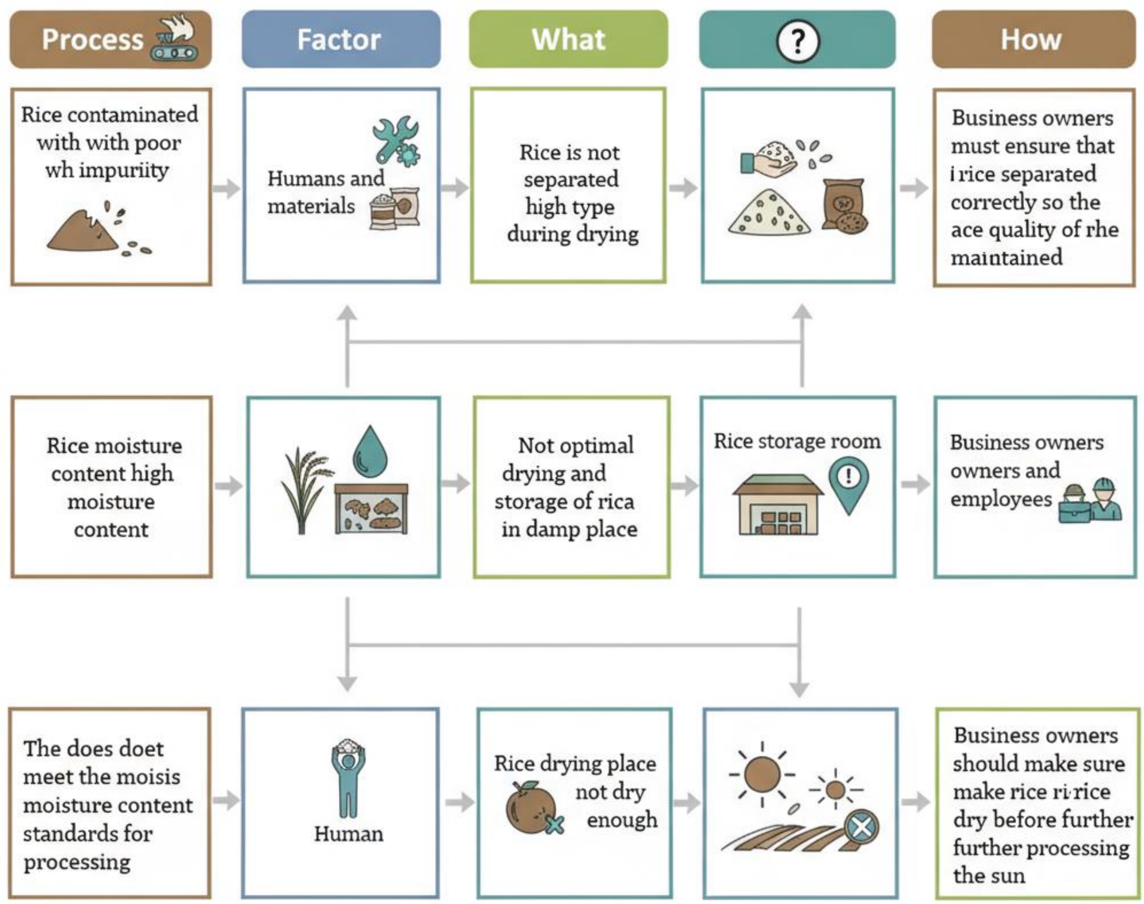
The production process has varied risks, with the "Machine not operating optimally" showing the highest RPN of 567 (ranked 1), emphasizing the importance of regular maintenance and machine performance checks to avoid substantial production losses. Other process-related failures such as "Suboptimal drying" and "Dirty drying place" yield moderate RPN values (60), indicating areas requiring improved environmental and operational controls.

Finished product concerns are also evident, with "Dirty rice" showing a significant RPN of 100 (ranked 6) and "Broken or incomplete rice grains" standing at an RPN of 80 (ranked 9). These failure modes underscore the importance of thorough cleaning, sorting, and careful handling during final stages to maintain product quality standards.

The FRPN ranking further supports prioritization by incorporating additional risk factors, and the infographic clearly displays both RPN and FRPN rankings for comparison, enabling a holistic view of risks at all stages: raw material, production process, and finished product.

5W+1H Improvement

The 5W + 1H proposal is an approach used to plan preventive actions against potential sources of defects in a production process. This approach involves six important questions: What (what is happening), to find out the situation at hand; Why (why did it happen), to analyze the cause; Where (where is the part that needs to be repaired), to identify the location of the problem; When (when should repairs be made), to determine the right time for action; Who (who is involved in the repair), to determine the responsible party; and How (how is the repair carried out), to formulate effective preventive and corrective measures. By using 5W + 1H, the repair process can be carried out in a more structured and targeted manner, thereby reducing the risk of product defects and improving the quality of production results.



The chain of events leading to rice quality problems using a factor-process-corrective action approach. The initial process shows that rice contamination occurs due to dirt and foreign matter caused by human and material factors, as well as suboptimal separation of rice types during the drying stage. In addition, high moisture content is also a major problem because the drying and storage processes are carried out under inappropriate conditions, such as in damp storage rooms. These conditions cause the rice to not meet the moisture content standards required for the next stage of processing. Human factors also play a significant role when the drying location is not dry enough, so that the moisture content of the rice remains high. To overcome these problems, business owners and workers need to ensure that the rice separation, drying, and storage processes are carried out correctly, including ensuring that the rice is completely dry before further processing. This narrative emphasizes the importance of implementing systematic quality control at every stage of rice production so that quality standards can be maintained in accordance with industry requirements.

DISCUSSION

This study applies the Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA) method to identify, classify, and mitigate risks in the rice milling production process [20]. The results show that the highest risk factor comes from machine failure, with a FRPN value of 827. This supports the findings [21], which confirmed that the Fuzzy FMEA method is more effective than conventional FMEA in handling linguistic uncertainty in risk data [22].

In line with this, [23] noted that the application of Fuzzy FMEA in the food industry can increase the accuracy of risk assessments by up to 30%. The highest results in this study came from machine factors, as also found [24], who revealed that 47% of failures in the coffee grinding process stemmed from machines that were not regularly maintained.

High moisture content in grain, which causes rice to turn yellow and become brittle, is also a major concern. [25] stated that moisture content >14% increases the likelihood of cracking and mold growth during storage. This study also noted that suboptimal drying is a major contributing factor, in line with the recommended drying duration of at least 18 hours in sunlight as studied by [26]

Cleanliness of the workplace and drying area is a crucial aspect of final product quality. A study [27] in the flour industry found that sanitation and separating raw materials based on quality can reduce product defects by up to 25%. In this context, the 5W+1H approach used in this paper is relevant to the findings of [28], who combined FMEA and 5W1H to design more structural improvements to the production system.

The use of MATLAB in fuzzy modeling provides accurate and consistent results. Research by [29] also demonstrated the effectiveness of MATLAB FIS Designer in risk simulation and defuzzification. Furthermore, [30] showed that transforming RPN values to FRPN often results in different risk priorities, indicating that fuzzy logic is more sensitive in capturing implicit variables.Early detection presents a unique challenge. In this study, low detection scores indicate the limitations of manual inspection. [27] recommend a sensor-based early warning system to improve detection accuracy. Poor end-product quality, such as dirty or yellowed rice, can erode consumer trust. [31] demonstrated that declining agricultural product quality impacts consumer loyalty by up to 35%.

Storage issues were also identified, particularly rice infestation due to humidity. [15] recommend controlled temperature and humidity storage to prevent infestation. Operator competence is also crucial. [8] emphasized that regular training on SOPs can reduce human error by 50%. Finally, recent developments by [9] show that the integration of Fuzzy FMEA with IoT technology enables real-time monitoring of humidity, temperature, and machine conditions, which could be a direction for further development for MSME-scale rice milling.

Research Implication

This study has several important implications, both theoretically and practically. Theoretically, the results of this study reinforce the literature on the effectiveness of the Fuzzy FMEA method in overcoming the limitations of conventional FMEA, particularly in dealing with linguistic uncertainty and subjectivity in risk assessment. The integration of fuzzy logic with MATLAB Mamdani inference shows that this approach is capable of producing more accurate and consistent risk priorities, which can be used as a reference for the development of risk management methodologies in the agro-industry and other industries.

In practical terms, this study makes a significant contribution to small and medium-sized enterprises (SMEs) in the rice milling sector. The findings on key risk factors—such as machine damage, high moisture content, and low rice quality—provide an empirical basis for developing more structured improvement strategies through the 5W+1H approach. Thus, this research can help SMEs improve the effectiveness of quality control, reduce production losses, and maintain consumer confidence.

CONCLUSION

This study applies the Fuzzy Failure Mode and Effect Analysis (Fuzzy FMEA) method to identify, analyze, and prioritize potential failures in the production process at the Mas Nun rice mill. Based on data collected through observation, interviews, and literature review, 14 types of potential failures were identified that affect the quality of rice production. The Risk Priority Number (RPN) calculation results indicate that the factor with the highest risk level is a machine that is not operating optimally, with an RPN value of 567 and an FRPN value of 827. Other high-risk factors include high moisture content in rice, poor grain quality, and a suboptimal drying process. By using the fuzzy method, the RPN calculation results were refined to produce a Fuzzy Risk Priority Number (FRPN) value, which provides a more accurate picture of risk by considering linguistic and numerical data. This process helps in setting priorities for handling potential failures more effectively. This study recommends the application of the 5W + 1H approach for each potential risk as a basis for taking corrective and preventive actions, so that rice quality can be improved and consumer confidence can be maintained.

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