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RESEARCH PAPER

Risk Evaluation in Corn Supply Chain with FMEA Approach: Challenges and Opportunities for Supply Efficiency

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ABSTRACT
The research focuses on improving the performance of the corn supply chain in Madura Island, Indonesia. The purpose of the study is to identify, evaluate, and prioritize risks that have the potential to disrupt the smooth operation of the corn supply chain. The research method uses Failure Mode and Effects Analysis (FMEA) to identify risk levels and Root Cause Analysis (RCA) approach for mitigation strategies. Risk level assessment is based on severity, probability, and detectability at the level of farmers, middlemen, processing industries, and distributors. Based on the analysis, it shows that the risks are a priority in handling and prevention as well as proposals that can be made to improve the root cause of the occurrence of risks with the highest category based on the RPN value at the farmer level are the occurrence of pest and disease attacks (648), the middleman level is when the amount of corn is abundant (336), the processing industry level is the price of corn is unpredictable (252), and the level of distributors is a limitation in product promotion (324). To improve the efficiency and quality of the corn supply chain, namely increasing storage capacity, using more efficient processing technology, flexible production planning, and more innovative marketing strategies. The managerial implications of corn-supply chain risk assessment are the need to improve product quality, corn supply stability, price management, and strengthen partnerships and mutual benefits between all parties in the supply chain. Every element of the supply chain needs to encourage the adoption of modern technologies in maize cultivation, processing, and distribution to increase productivity and reduce risks associated with manual processes. It is necessary to establish mitigation strategies to address environmental risks, including the implementation of sustainable agricultural practices and early warning systems.

KEYWORDS: *Corn; FMEA; Mitigation; Supply chain; Risk evaluation.*

1. Introduction

Corn is a strategic food commodity that plays an essential role in food security, animal feed, and industrial raw materials in East Java, Indonesia [1]. As one of the primary sources of carbohydrates, the demand for corn continues to increase along with population growth and the development of the industrial sector. Some regions use corn as the primary food source. The availability of corn needs to be maintained in terms of quantity and price stability. Madura Island is the largest Corn-producing region in East Java, Indonesia. The area of Madura suitable for corn cultivation is 70,279.5 ha or 15.4% of the area of Madura [2, 3]. Despite having considerable production potential, the corn supply chain in Madura faces various challenges that increase the risk of the production and distribution process [4]. The corn supply chain is a complex network involving various stakeholders, from farmers, traders, and storage to end consumers.

The corn supply chain in Madura also faces constraints at the distribution level, including price fluctuations due to unstable supply and lack of adequate storage facilities, which causes a decrease in corn quality. Risks in the corn supply chain in Madura start from production to distribution. Risks in the corn supply chain include a variety of factors that can affect the availability and quality of products from farmers to consumers. Based on the latest research, the following are some of the main risks in the corn supply chain, including (a) Natural factors, namely weather, and pests; (b) the length of the distribution chain from farmers to consumers leads to inefficiencies that can increase costs and reduce profit margins for farmers. Logistics issues, such as delivery delays and inadequate infrastructure, are also significant challenges; (c) distribution levels, including price fluctuations

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due to unstable supply and lack of adequate storage facilities, which lead to a decline in maize quality; (d) Instability in market demand is also a risk factor, where abundant supply at one time can cause prices to fall, while a lack of supply can cause prices to soar [5, 6]. Technological improvements are needed to monitor market developments and facilitate business operations, such as online marketing platforms, to reduce the influence of intermediaries and increase direct sales [7, 8]. These risks include quality issues, contract issues, and financial implications. Barren natural conditions, dependence on rainfall, and the use of limited agricultural technology are some of the factors that affect corn productivity in this region [8]. Risk is the potential for unwanted events caused by the uncertainty of the occurrence of an event.

Another problem is the existence of a middleman. The existence of middlemen is a significant problem for farmers. Farmers often have to sell products to middlemen at low prices, who then sell them to consumers at higher prices. This problem will reduce farmers' profits and increase consumer costs. Dependence on collectors lengthens the distribution channel and has the potential to depress the prices received by farmers. The supply chain involves many parties, from material suppliers, production, customer demand, transportation, warehousing, distribution, and others, to ensure that finished products reach consumers properly. Risk evaluation in the corn supply chain is essential to ensure efficiency and continuity of supply [6].

Infrastructure in the Madura region causes logistical challenges that further complicate the distribution process. Limited infrastructure, such as inadequate roads in rural areas and difficult transportation access, are often obstacles to distributing corn from local farmers to broader markets. These limitations disrupt the corn supply chain [9]. In addition, to develop corn products into high-value commodities, added value is needed by producing other products [10].

On the other hand, agricultural supply chain risk management is different from manufacturing-product supply chain risk management: (1) agricultural products are perishable, (2) the planting, growing, and harvesting processes depend on climate and season, (3) the harvest has various shapes and sizes, (4) agricultural products are loose, so agricultural products are challenging to handle. Agricultural supply chain risk management becomes more difficult due to several sources of uncertainty and complex relationships between actors in the supply chain [11, 12].

Based on these conditions, research on the efficiency of corn commodity marketing channels in Madura is needed. Through this research, the proportion of profit distribution of each institution in each marketing channel, the price formation process, and alternative channels that can be maximized to increase corn farmers' income will be seen. Therefore, it is necessary to identify risks at each level of the supply chain, measure supply chain risks, and mitigate supply chain risks to support appropriate and efficient decision-making in supply chain management at each level. Several efforts have been made to manage risks that may affect the corn industry. Among them are cooperation between farmers and companies, determination of corn selling prices, and cooperation between farmers and agricultural extension workers.

One effort that can be made to reduce failures in supply chain management is to implement sound risk management [13]. Risk management helps in identifying, analyzing, and managing risks that may occur along the supply chain so as to prevent significant negative impacts on business operations and sustainability [14]. By understanding potential risks, companies can create more effective mitigation plans, optimize processes, and increase supply chain resilience to disruptions [15–19].

One method that is often used in supply chain risk management is Failure Mode and Effect Analysis (FMEA) [20]. FMEA is a systematic approach that aims to identify potential failures at each stage of the process, analyze the causes and impacts, and set priorities for handling based on risk levels. Through FMEA, companies can focus more on critical areas that have high risks so that mitigation efforts can be implemented more precisely. The application of FMEA not only helps reduce the frequency of failures but also improves process reliability in meeting market demand and maintaining product quality [21–23]. The Failure Mode and Effect Analysis (FMEA) method has several advantages in identifying supply chain risks. One of its advantages is its ability to proactively identify potential failures before problems occur, allowing companies to take preventive measures earlier. FMEA also provides a structured analysis, where each potential failure is identified along with its causes, impacts, and priorities based on risk scores [24, 25]. Thus, this method makes it easier for management to determine areas that need more attention to reduce the most potentially detrimental risks [26]. In addition, FMEA helps improve collaboration between parts of the company. The FMEA process usually involves cross-functional teams so that various perspectives can be gathered to understand the risks more comprehensively [24]. By involving various departments, risk identification becomes more accurate, and the resulting solutions are more effective. FMEA is also flexible and can be applied to various stages in the supply chain, from raw material procurement to final product distribution. These advantages make FMEA a reliable and efficient method for improving supply chain resilience and performance [27].

Another study using the Failure Mode and Effect Analysis (FMEA) method for supply chain risk analysis showed how FMEA can be applied in various industries to identify and mitigate risks. FMEA was used to identify risks associated with product deletion in the supply chain, highlighting the top ten risks and providing managerial recommendations for risk control and elimination [26]. The integrated FMEA and analytical hierarchy process (AHP) approach prioritized risks that caused downtime and financial impact, with unique supply sources identified as the primary risk [28]. The FMEA and FMEA-TOPSIS methods identified and prioritized procurement risks, such as delays in the supply of imported spare parts, and suggested new controls for better decision-making [29]. The fuzzy FMEA model evaluated risks in warehouse operations, considering the relative importance of events, severity, and detection factors [30–32]. FMEA can also be used to identify and prioritize risks in the agricultural supply chain [33, 34]. FMEA also plays an essential role in formulating risk mitigation strategies in the shallot supply chain [35]. In another study, it was proposed that FMEA can be used to determine mitigation strategies, namely branding image and market penetration, with production capacity adjustments being the main priority [33, 36, 37].

Based on literature studies and actual conditions in the field, this research is essential to improve the performance of the corn supply chain in Madura. Improving supply chain performance will have an impact on increasing the income of each element of the corn supply chain. The study aims to identify key risks, assess the severity, probability, and detectability of each risk, and provide recommendations to mitigate priority risks using the FMEA approach. In the study, one of the risk management methods used by researchers to analyze corn supply chain risk is the FMEA method. The risk assessment stage mainly uses the FMEA method with a Risk Priority Number (RPN) based on three leading indicators, namely the severity of losses due to risk, the frequency of risks, and the difficulty of detecting risks. Corn supply-chain risk analysis using the FMEA method is essential because it can identify and prioritize risks that have the potential to disrupt the smooth running of the supply chain. The risk assessment obtained from the FMEA method carries out mitigation actions to reduce the negative impacts caused. Mitigation measures use the Root cause analysis (RCA) approach. RCA is a method for finding the root cause of a problem, which can be used for mitigation measures. RCA can help prevent the same problem from happening again by identifying the proper precautions. The benefits of RCA for mitigation measures are to prevent the same problem from recurring, increase efficiency and productivity, increase customer satisfaction, improve safety and quality, and increase customer trust.

2. Material and Methods

The study was conducted on Madura Island, Indonesia, which consists of 4 regencies, namely Bangkalan, Sampang, Pamekasan, and Sumenep. Each regency took 4 sample villages (a total of 16 villages). The determination of the area was made intentionally (purposively), considering that these villages are one of the centers of corn production. The sample of farmers was 43 farmers. Data collection was carried out through interviews using a questionnaire. Data collection was also carried out with documentation to collect secondary data from government agencies and related institutions. This study was conducted at the farmer, middleman, processing industry, and distributor levels.

The FMEA approach is most often used when it is intended to design or implement new products, services, processes, methods, or actions to meet the intended goals of the organization, where errors and the amount of risk are not adequately identified [38]. In this study, the FMEA method was used because of the risk assessment of corn supply chain failure. This procedure is carried out to prevent failure (before it occurs) with seven basic steps as follows: Identifying activities in the corn supply chain; (2) Identifying error modes; (3) Determining the difficulty of the error mode (intensity) using a ranking technique with difficulty levels ranging from 1 to 10; (4) Determining the probability of occurrence of one of the error modes indicating the most negligible probability of 1 and the number 10 indicating the probability of occurrence; (5) Determining the possibility of detection; (6) Calculating the Risk Priority Number (RPN) calculated for each error mode from the multiplication of three quantitative ratings, namely risk impact (severity), possibility of occurrence (occurrence), and detection (detection) (Table 1); (7) Determining control actions to reduce the impact and possibility of risk occurrence with Root cause analysis (RCA) approach.

The Risk Priority Number (RPN) assessment formula is as follows [39]:

$$\text{RPN} = \text{SxOxD} \quad (1)$$

After calculating the RPN value, the critical value of the RPN can then be calculated. The critical value can be used to determine the risks that will be prioritized. The critical value is obtained from the total number of RPN values divided by the number of risks as in the following formula:

$$\text{RPN critical} = \frac{\text{Total RPN}}{\text{Total Risk}} \quad (2)$$

The severity value reflects the severity of the impact of a potential failure or loss for each risk indicator. The occurrence value represents the probability or likelihood of a failure or loss for each risk indicator. In contrast, the detection value indicates the level of availability of detection systems for the impact of potential failures for each risk indicator (Table 2).

3. Result and Discussion

3.1. Risk evaluation

3.1.1. Identification of corn damage at the farmer level

The risk of damage at the farmer level is analyzed to determine the factors that farmers must face in supply chain management to improve the quality of corn products. The sources of risk obtained at the farmer level are the dosage of fertilizer and pesticide use, types of fertilizer and pesticides, farmers' ability to purchase production facilities, high production costs, and the influence of weather that cannot result in low corn quality. Identification of the Risk of corn damage at the farmer level can be seen in Table 3.

3.1.2. Identification of corn damage at the middleman level

The results of risk identification at the collector level are uncertainty and fluctuations in corn prices, warehouse capacity during the harvest season, varying quality of corn supply, and conditions during the main corn harvest. The highest risk at the collector level is damaged corn during the rainy season with high intensity.

Tab.1. Criteria for the probability of occurrence, severity, and detection

Score	Occurrence	Severity	Detection
1	Very unlikely to occur Unlikely to occur	Very low—will not affect the process. Low—may affect the process	Certain—faults will be caught on test High
2/3	May occur about half of the time Likely to occur	Medium—slightly affects the process. High—mostly affects the process	Moderate Low
4/5	Very likely to occur	Very high—definitely affects the process	Fault will be passed to the customer undetected
6/7/8	Very unlikely to occur Unlikely to occur	Very low—will not affect the process. Low—may affect the process	Certain—faults will be caught on test High
9/10	May occur about half of the time Likely to occur	Medium—slightly affects the process. High—mainly affect the process	Moderate Low

Tab.2. Risk category based on RPN value

No	RPN	Category
1	192-1,000	High (Require Risk Control Actions)
2	65-191	Medium (Reduce Risk to as Low as Reasonably Practical)
3	8-64	Low (Acceptable Risk)

Tab.3. Identification of corn damage risks at the farmer level

Cause of Damage	Problems That Arise	Effect
No measurements in using fertilizers and pesticides	Land fertility decreases	Low corn quality
Pest and disease attacks	Plants are attacked by pests and diseases	Low corn quality
Farmers' ability to purchase production inputs	Falsification of fertilizers and pesticides	Low corn quality
High production costs	Low selling prices	Farmers experience losses in the production process
Flooded during the rainy season	Low corn quality, especially the rainy season	High moisture contens

Collectors buy corn from farmers with corn that has a water content of 15% so that it does not need to be dried in the warehouse, while in the rainy season, the water content of the corn becomes higher, and the quality varies. Identification of corn damage at the middleman level is presented in Table 4.

3.1.3. Identification of corn damage at the processing business level

The corn supply chain at the processing industry level is an industry that carries out the process of sorting, drying, milling, and packaging Corn. The results of risk identification at the processing industry level can be seen in Table 5.

3.1.4. Identification of corn damage at the distributor level

A corn distributor is an institution that distributes and sells corn products to consumers. The results of risk identification at the distributor level can be seen in Table 6.

3.1.5. Risk priority Number (RPN) assessment

The data obtained contains a failure list recorded in the Failure Mode and Effect Analysis (FMEA) system for each element of the corn supply chain. Data collection is needed to find out potential failure mode data information and determine severity, occurrence, and detection values. The next stage is to determine the RPN (Risk Priority Number), which is an essential part of FMEA because the RPN value determines the risk priority that is included in the critical risk [40]. The assessment is carried out by experts using scores ranging from 1 to 10 for various risks that are considered to produce a false and unrealistic impression. A score of 1-10 for the occurrence value is improbable to occur to very likely to occur.

Tab.4. Identification of corn damage risks at the middleman level

Cause of Damage	Problems That Arise	Effect
Uncertainty and fluctuation of corn prices	Corn prices are falling	Middlemans buy from farmers at low prices
Warehouse capacity during harvest season	Corn storage is inadequate	Post-harvest corn handling is not appropriate
Rainy season	Corn quality varies	Handling costs are needed, especially for the drying process
Variable quality of corn supply	A sorting process is needed	Requires higher handling costs
Main harvest season	Corn is abundant, while drying equipment is limited, relying on sunlight	The corn drying process takes longer

Tab.5. Identification of corn damage risks at the processing industry level

Cause of Damage	Problems That Arise	Effect
Corn demand is unpredictable.	Corn demand is not met	Many requests are pending.
The sorting process for receiving raw materials is poor	Low corn quality	The quality of corn is not uniform
Lack of maintenance of production machines and equipment	The milling process is not smooth	There is a relatively long delay process
Price fluctuations	The purchase price of raw materials and product sales are unpredictable	Requires high reserve costs to anticipate price fluctuations
Milling errors	Product quality is not optimal	The quality of corn is not up to standard

Tab.6. Identification of corn damage risks at the distributor level

Cause of Damage	Problems That Arise	Effect
Small-capacity storage warehouse	Many corns are not stored in the warehouse, especially during the peak harvest season.	Corn quality cannot last long due to improper storage.
Limitations in product promotion	The number of buyers is constant	Sales volume does not increase
Decrease in quality of corn production.	Lack of corn supply that meets quality standards	Return of poor-quality products
Fluctuation in corn prices	Changes in the amount of demand	Unable to predict product prices and inventory
Error in estimating the amount of demand	Many requests are not met, or corn piles up in the warehouse	

In comparison, a score of 1-10 for the severity value is very low (will not affect the process) to high (primarily affects the process). For a score of 1-10, the detection value is specific to occur (high level of detected errors) to low [41]. The results of the assessment of each potential risk are shown in Table 7, Table 8, Table 9, and Table 10. The RPN value (192-1000) is included in the High category (Require Risk Control Actions); A value of 65-191 is the Middle category (Reduce risk to as Low as Reasonably Practical); and a value of 8-64 is the Low criteria (Acceptable Risk) [41].

Based on Table 7, several causes of damage are of primary concern in corn cultivation. The most critical problem is pest and disease attacks on plants, which have the highest RPN value (648). The pest and disease attacks have a significant impact on corn productivity and need to be prioritized in risk management. This problem indicates that pest and disease control efforts must be the main focus so that losses can be minimized. The findings of this research are in accordance with the findings of other researchers who stated that diseases in corn plants caused by fungi, bacteria, viruses, and environmental conditions can result in reduced productivity and even crop failure if not identified and managed productively [42, 43]. Furthermore, high production costs are also a significant problem. The low selling price of corn also causes the profits obtained by farmers to decrease. High production costs that are not balanced with selling prices require farmers to be more efficient in managing costs or find alternatives to increase selling prices so that the sustainability of farming businesses can be maintained. Farmers' ability to purchase production inputs also has a significant impact, primarily related to the counterfeiting of fertilizers and pesticides, with an RPN value of 216. Lack of access to quality production inputs makes farmers more vulnerable to the use of counterfeit products that can harm crops [44].

Tab.7. RPN assessment at the farmer level

Cause of Damage	Problems That Arise	Assessment			
		S	O	D	RPN
No measurements in using fertilizers and pesticides	Land fertility decreases	6	9	2	108
Pest and disease attacks	Plants are attacked by pests and diseases	9	8	9	648
Farmers' ability to purchase production inputs	Counterfeiting of fertilizers and pesticides	6	6	6	216
High production costs	Low selling prices	6	9	7	378
Flooded during the rainy season	Low corn quality, especially during the rainy season	3	6	2	36

Tab.8. RPN assessment at the middleman level

Cause of Damage	Problems That Arise	Assessment			
		S	O	D	RPN
Uncertainty and fluctuation of corn prices	Corn prices are falling	8	6	3	144
Warehouse capacity during harvest season	Maize storage is inadequate	8	3	5	120
Rainy season	Corn quality varies	3	6	6	108
Variable quality of corn supply	A sorting process is needed	3	3	6	54
Main harvest season	Corn is abundant, while drying equipment is limited, relying on sunlight	6	8	7	336

Tab.9. RPN assessment at the processing industry level

Causes of Damage	Emerging Issues	Assessment			
		S	O	D	RPN
Corn demand is unpredictable	Corn demand is not fulfilled	6	8	4	192
The sorting process at the receipt of raw materials is not good	Corn quality is low	3	2	4	24
Poor maintenance of production machinery and equipment	Non-smoothness of the grinding process	4	4	5	80
Fluctuating prices	Raw material purchase prices and product sales are unpredictable	7	6	6	252
Error in milling,	Product quality is not maximized	6	7	5	210

Tab.10. RPN assessment at the distributor level

Causes of Damage	Emerging Issues	Assessment			
		S	O	D	RPN
Small-capacity storage warehouse	Large amounts of corn are not stored in warehouses, especially during the harvest season.	6	3	2	36
Lack of product promotion	Constant number of buyers	9	6	6	324
Decreased quality of Corn production	Lack of Corn supply that meets quality standards	4	3	5	60
Corn price fluctuations	Change in demand amount	9	6	4	216
Misestimation of demand	Many demands are not fulfilled, or corn is piled up in the warehouse	7	6	4	168

In the long term, this counterfeiting can reduce land productivity and the quality of the harvest. Flooding during the rainy season also causes corn quality to decline, especially in terms of seed quality, with an RPN value of 36. Although this risk is relatively low, flood control or good drainage is still needed to maintain the quality of the harvest.

Table 8 shows the risk priority number (RPN) assessment at the middleman level, with the highest RPN value during the peak harvest season (336). During this season, corn is abundant, but the drying equipment available is limited, so middlemen can only rely on sunlight for the drying process [45–47]. This limitation has the potential to reduce the quality of corn and cause losses if the harvest is not processed correctly. The price of corn often fluctuates, causing uncertainty, so middlemen have to face the risk of price declines, which can have a negative impact on middlemen's profits [48–51]. Limited warehouse capacity forces middlemen to store corn as much as they can, which can affect the quality of corn during storage. Increasing storage capacity is very important so that the middleman can maintain the quality of corn and reduce the risk of damage during storage.

Overall, the main obstacles faced by middlemen are during the peak harvest season and price fluctuations. With improvements in storage capacity and provision of drying equipment, as well as price risk management, it is expected that the quality of corn distributed by middlemen can be better maintained and generate stable profits.

Table 9 indicates the Risk Priority Number (RPN) assessment at the Corn processing industry level. The cause of damage that affects the quality and sustainability of the production process is fluctuating prices, with an RPN value of 252. This price fluctuation causes uncertainty in the purchase of raw materials and product sales, which impacts the stability of industry profits [51]. Therefore, price-related risk management becomes an essential priority in maintaining business sustainability. Errors due to the milling process led to the quality of the products produced not being maximized, so quality control in the milling process needs to be improved to ensure that the products produced meet the expected standards [52]. Corn demand, which cannot be predicted, is also a challenge for the industry, with an RPN value of 192. This demand uncertainty potentially makes it difficult for the industry to meet the fluctuating needs of corn, so a more flexible and adaptive production planning strategy is needed to adjust supply to market demand.

In most cases, the Corn processing industry needs to focus on managing price risk, quality control in the milling process, and increasing flexibility in demand planning. With proper risk management, the industry hopes to increase production efficiency and maintain the quality of the products produced.

Table 10 indicates that the highest RPN value is limitations in product promotion, with an RPN value of 324. This lack of promotion causes the number of buyers to remain constant, so the market potential cannot be maximized. Distributors need to consider more effective promotional strategies to increase product appeal and reach more buyers [54, 55]. These price fluctuations have an impact on changes in demand, which can make it difficult for distributors to adjust supply to market needs [56, 57]. Therefore, consistent price monitoring and flexibility in inventory management are essential to anticipate changes in demand. Although the impact is relatively small, limited warehouse capacity can prevent corn from being stored optimally, especially during peak harvest seasons. Increased warehouse capacity or better storage management is needed to anticipate supply surges.

In general, the main challenges at the distributor level are product promotion, price fluctuations, and demand estimation errors. By improving on these aspects, distributors are expected to increase distribution efficiency, maintain supply quality, and optimize Corn availability in the market.

3.2. Cause-effect diagram for corn supply chain risk

Identification of the causes of risks in corn's supply chain may be conducted through a cause-and-effect analysis covering several key factors: people, methods, materials, machinery, environment, and management. In terms of human factors, risks arise from farmers' limited knowledge of the correct dosage of fertilizers and pesticides, as well as a lack of training in crop management and pest control. In addition, limited labor, especially during harvest season, and lack of access to information on market prices and demand also have the potential to increase risk.

Method factors also affect risk in the supply chain. Inadequate storage techniques, especially at the middleman and distributor levels, and suboptimal inventory management often lead to errors in estimating stock requirements. In addition, inconsistencies in the milling process affect the quality of the final product, and limited product promotion reduces corn's market reach.

Regarding material factors, variations in corn quality are a source of risk as substandard seeds can reduce yields. Adulteration of fertilizers and pesticides often found in the market adds risk at the cultivation stage. In addition, the fluctuating availability of quality seeds and the varying quality of Corn supply from farmers also cause instability in the supply chain.

Machinery factors include limited storage and drying equipment, especially during the peak harvest season when corn is abundant. Sub-optimal tool maintenance leads to breakdowns in milling machines and other equipment, hampering smooth production. Reliance on manual tools and lack of modern processing technology also result in inefficiencies, especially in the drying process in the rainy season.

Environmental factors play a significant role as market price fluctuations may cause uncertainty in sales. In addition, the rainy season increases the Risk of Corn quality deterioration due to storage issues and poor soil conditions. Natural disasters such as floods can also damage crops and reduce Corn yields.

In the management factor, risks arise from poor production planning, so market needs are not always met. Lack of quality control along the supply chain also causes products not always to meet standards. The lack of innovative marketing strategies and limited logistics infrastructure worsen the efficiency of Corn distribution and storage.

Cause-effect diagrams are used on the Corn supply chain to determine appropriate mitigation measures to reduce risks and ensure smooth distribution from upstream to downstream.

3.3. Risk mitigation

Efforts that can be made to reduce the risk of damage to the corn supply chain require implementing mitigation strategies at each level of the supply chain. At the farmer level, it is crucial to provide guiding sessions on the proper use of fertilizers and pesticides to maintain land fertility and crop quality. Training on pest and disease control is also needed to reduce the risk of infestation. In addition, the use of more efficient and environmentally friendly agricultural technologies can reduce dependence on harmful pesticides and increase productivity. Optimal production planning is also vital to avoid damage from extreme weather conditions, while adequate access to financing helps farmers purchase quality inputs, avoiding reliance on potentially counterfeit products.

At the broker level, increased storage capacity is urgently needed, especially during the peak harvest season, to maintain Corn quality and avoid uncontrolled accumulation. Mechanical dryers or solar dryer systems can also maintain the quality of corn during the harvest season. Price stabilization could be performed by establishing cooperation with suppliers and farmers to set a more stable price range, reducing the impact of extreme market price fluctuations. In addition, more intensive and effective promotion will help improve marketing networks and attract more potential buyers.

For the processing industry level, better inventory planning with accurate demand analysis will help the industry anticipate changes in demand and avoid overstocking or understocking. Regular machine maintenance is also essential to ensure a smooth production process, especially at the milling stage. Stricter sorting processes and implementation of quality control standards will maintain the quality of processed corn. Long-term contract arrangements with Corn raw material suppliers can also maintain supply and price stability so that the risk of price fluctuations can be minimized. At the distributor level, the use of historical data and market trends for more accurate demand forecasting will reduce estimation errors. Optimizing warehouse capacity with an efficient warehouse management system could avoid product accumulation and ensure that corn remains stored in good condition. Regular product promotions can attract more buyers and maintain price stability, while collaboration with other retailers or distributors can expand distribution reach and optimize available supply in the market. By implementing these strategies, risks in the Corn supply chain can be minimized so that the sustainability of supply and quality can be maintained.

4. Conclusion

Risk identification in the corn supply chain occurs at the level of farmers, middlemen, processing industries, and distributors. The sources of risk obtained at the farmer level are the amount of fertilizer and pesticide used, the type of fertilizer and pesticide, the ability of farmers to buy production facilities, high production costs, and the influence of weather that cannot result in low corn quality. Risks at the collector level are uncertainty and fluctuations in corn prices, warehouse capacity during the harvest season, varying quality of corn supply, and conditions during the corn harvest. The corn supply chain at the processing industry level is an industry that carries out the process of sorting, drying, milling, and packaging corn. Meanwhile, the risk at the distributor level is an institution that distributes and sells corn products to consumers.

Based on the analysis that has been carried out using the FMEA (Failure Mode and Effect Analysis) and RCA (Root Cause Analysis) shows the risks that are a priority in handling and prevention as well as proposals that can be made to improve the root cause of the occurrence of high category risks (RPN ranges from 192–1000) at the level of farmers, middlemen, processing industries and distributors. The assessment of the risk level at the farmer level is the occurrence of pest and disease attacks (648), the ability of farmers to buy production facilities (216), and the high cost of production (378). At the middleman level, with an RPN value of 336, the amount of corn is abundant, while the limited drying equipment relies on sunlight. At the level of the processing industry, there are demand (192), unpredictable corn prices (252), and errors in the corn milling process (210). The highest level of risk at the distributor level is limitations in product promotion (324) and unpredictable corn prices (216). Mitigation strategies need to be implemented to reduce risks at the farmer level, namely by providing education about pest and disease control and the use of agricultural technology that is more efficient and environmentally friendly. The middleman-level mitigation strategy is to increase the storage capacity and use of mechanical dryers, as well as the cooperation of suppliers and farmers, to establish a more stable price range. At the processing industry level, the mitigation strategy is carried out by periodically maintaining the milling machine. Meanwhile, at the distributor level, it is necessary to use more accurate demand forecasting techniques to reduce estimation errors, optimize warehouse capacity with an efficient warehouse management system, and promote more attractive products.

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Conflict of Interest

The author declares that there are no conflicts of interest regarding the authorship or publication of this research.

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