Analysis of development strategy and risk mitigation for smoked striped catfish (*Pangasianodon hypophthalmus* (Sauvage, 1878)) processing industry in the Fishery Product Processing Center of Koto Mesjid Village: An integrated SWOT-HOR approach for local agro-industry sustainability

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Abstract. The smoked striped catfish (*Pangasianodon hypophthalmus* (Sauvage, 1878)) processing industry at the Fishery Product Processing (PHP) Center in Koto Mesjid Village, Riau, plays a crucial role in the local economy despite facing challenges in production quality, risk management, and sustainability. This empirical study, conducted from July to December 2023, aims to analyze the industry's strategic position, identify key risks, and formulate appropriate development strategies. Combining SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis and the House of Risk (HOR) method, data were collected through field observations, in-depth interviews with 30 industry stakeholders, and structured surveys. The SWOT analysis reveals that the industry occupies a robust strategic position (Quadrant I), with dominant strengths in high-quality production and increasing market demand, indicating significant growth potential. The HOR analysis uncovers substantial risks associated with poor quality control and reliance on traditional processing methods. Priority strategies recommended include implementing a quality management system (ISO 9001), adopting Good Manufacturing Practices (GMP), modernizing production technology, and developing environmentally friendly practices. Emphasizing human resource capacity development and integrating the industry with the local economy through ecotourism are also crucial. In conclusion, the smoked striped catfish processing industry has substantial growth potential, provided that appropriate strategies are implemented to address internal weaknesses and external challenges. This research contributes to policy formulation for developing small and medium-scale fishery industries, with significant implications for regional economic development and food security.

Key Words: smoked striped catfish, risk management, SWOT-HOR analysis, production sustainability, local economic development.

Introduction. The smoked fish process industry, particularly the production of pangasius fish, plays a vital role in Indonesia's economy, especially within the fisheries and marine sectors. Koto Mesjid Village, located in the XIII Koto Kampar District of Riau Province, is renowned as "Pangasius Village" due to its status as a significant center for high-quality smoked pangasius production (Kabupaten Kampar 2020). The village's Fishery Product Processing Center (PHP) is a cornerstone of the local economy, producing up to 1,500 tons of smoked pangasius annually (Kampar 2020). Pangasius is favored as the primary commodity because of its advantageous characteristics, including rapid growth, thick flesh, and a distinctive flavor post-smoking (Setiawan & Nurhayati 2018). Additionally, the growing market demand, both domestically and internationally, elevates pangasius as a high-value commodity (Rahman et al 2019). However, despite this significant potential, the smoked pangasius processing industry in Koto Mesjid faces numerous challenges that hinder its development.

One of the main challenges is ensuring product quality and food safety. Many processing methods in the industry still rely on traditional approaches, often neglecting the sanitation and hygiene standards outlined in Good Manufacturing Practices (GMP) (Sari et al 2019). This oversight increases the risk of microbial contamination, leading to a decline in product quality, eroding consumer trust, and limiting export potential (Widyaningsih & Pratiwi 2020). Furthermore, inadequate waste management practices contribute to environmental pollution, posing risks to aquatic ecosystems, soil quality, and the local community's health (Putri & Kurniawan 2018; Wijaya et al 2020).

Social aspects, particularly worker welfare, are also significant concerns. Unhealthy competition and a lack of stakeholder coordination can lead to social conflicts, affecting industry stability and community welfare (Sudirman & Aziz 2020). Low levels of education and insufficient training in good processing practices contribute to poor product quality and a lack of awareness about environmental sustainability (Dewi et al 2019).

Addressing these complex issues requires a comprehensive and systematic risk management approach to identify, assess, and mitigate various risks. Implementing ISO 31000:2018, an international risk management framework is not merely an option but a necessity for organizations like the smoked pangasius processing industry (International Organization for Standardization 2018). Adopting this standard is crucial as it can significantly enhance product quality, operational efficiency, and environmental sustainability (Mustafa & Abdullah 2020). In this context, conducting a SWOT (Strengths, Weaknesses, Opportunities, Threats) analysis is invaluable for identifying internal and external factors influencing the industry (Helms & Nixon 2010).

Moreover, the House of Risk (HOR) method, developed by Pujawan and Geraldin (2009), offers a structured approach to supply chain risk management. HOR integrates the House of Quality (HOQ) model and Failure Mode and Effects Analysis (FMEA) to identify risk sources and develop effective mitigation strategies. The HOR process involves two stages: HOR1 for identifying and ranking risk factors and HOR2 for creating risk mitigation strategies (Pujawan & Geraldin 2009). While SWOT and HOR methods have been widely applied across various industries, their integration within the context of the smoked pangasius processing industry in Koto Mesjid Village has not been extensively explored in the literature. There is a critical need for further research to assess the applicability of the HOR method in small and medium-sized enterprises, such as those in Koto Mesjid Village (Wahyuni & Susanto 2019).

Furthermore, previous studies have not thoroughly integrated ecological, economic, and social factors into a comprehensive risk management framework (Nurhayati et al 2018). Therefore, this study aims to address this gap by examining the use of risk management through a combination of SWOT analysis and the HOR method in the smoked pangasius processing industry at the PHP Center of Koto Mesjid Village. By identifying significant risks and devising effective mitigation strategies, we aim to develop a sustainable and practical risk management model that could benefit similar industries in other regions (Yusuf et al 2019).

Material and Method

Description of the study sites. This research was conducted at the Freshwater Fish Processing Center in Koto Mesjid Village, XIII Koto Kampar District, Kampar Regency, Riau Province, over six months from July to December 2023. Koto Mesjid Village was chosen as the research site due to its prominence as a central hub for the smoked catfish processing industry in the region (Kampar Regency 2020). This location provides an appropriate setting for examining various aspects of the smoked striped catfish processing industry, including potential ecological, economic, and social risks.

The presence of the processing center in this village enabled researchers to conduct direct observations of the production process, interact with industry stakeholders, and assess the environmental and socio-economic impacts generated by these industrial activities. Additionally, the accessibility of this location facilitated data collection through interviews with industry participants and direct observation of the local community dynamics involved in the smoked striped catfish production chain.

The six-month study allowed researchers to collect comprehensive data across different production seasons. This extended period enabled the capture of fluctuations and long-term patterns within the industry, providing a more nuanced understanding of its operations and impacts. Consequently, Koto Mesjid Village serves as an ideal natural laboratory for an in-depth study of the smoked striped catfish processing industry and its implications for sustainable development at the local level.

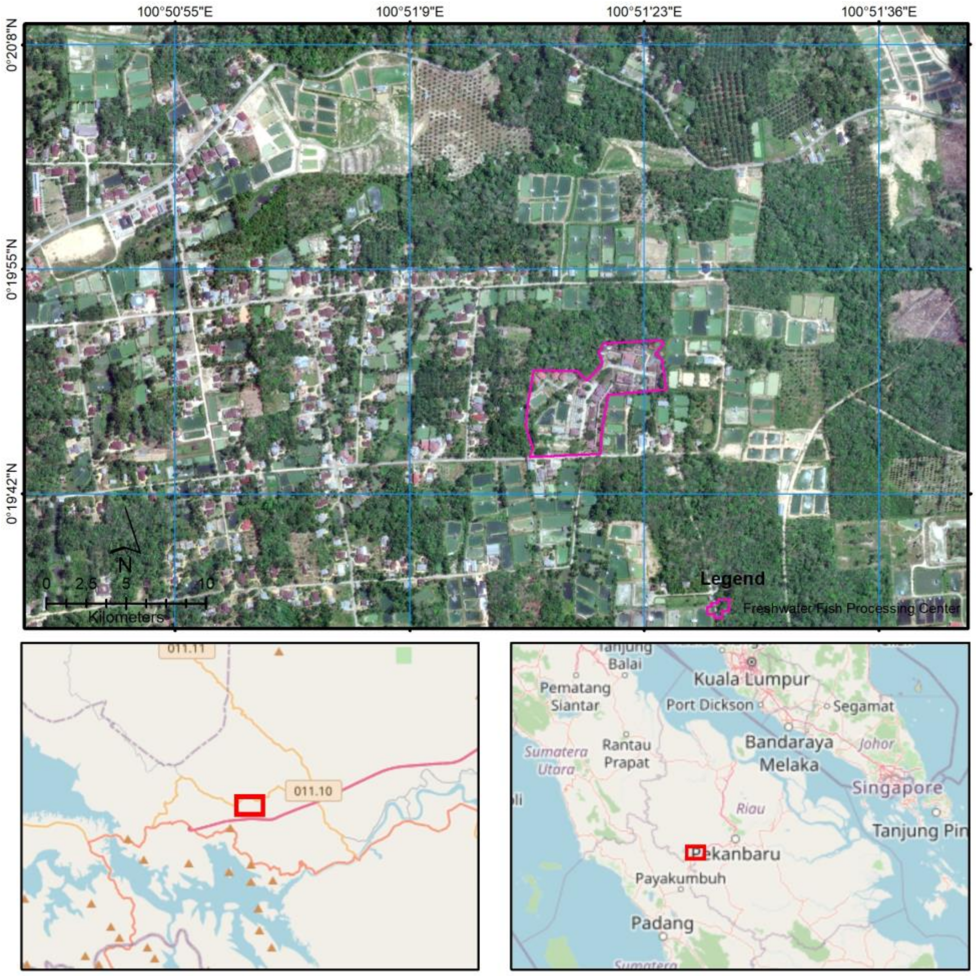

Figure 1. Map of the research location at the Freshwater Fish Processing Center in Koto Mesjid Village, XIII Koto Kampar District, Kampar Regency, Riau Province, Indonesia. This village is a central hub for the smoked striped catfish processing industry, providing an ideal setting for examining the industry's ecological, economic, and social aspects.

Data collected. This research utilized both primary and secondary data sources. Primary data were obtained through three main methods: direct observations, in-depth interviews, and structured questionnaires. Direct observations utilized standardized checklists adapted from industry risk management protocols (Tzeng & Chang 2011), focusing on production processes, work environment conditions, and waste management practices. In-depth interviews engaged 30 industry participants selected using purposive sampling techniques (Etikan et al 2016), comprising 10 respondents of production unit owners. 15 production workers and five local fisheries officials. The stakeholder selection criteria included a minimum of five years of experience in the industry, direct involvement in production processes, comprehensive knowledge of industry operations and challenges, and authority in decision-making processes. The structured questionnaires underwent validation through expert assessment and pilot testing with 10 respondents representing different stakeholder groups, achieving a Cronbach's alpha value exceeding 0.7. Environmental parameter measurements employed calibrated equipment following ISO 17025 standards, including digital thermometers for temperature (accuracy ± 0.1°C), calibrated pH meters, TDS meters for Total Dissolved Solids, and the Air Quality Detector Model T-Z01Pro for air quality measurements following WHO protocols (WHO, 2021). Secondary data collection accessed various official sources, including reports from the Kampar Regency Fisheries Office (2020-2023), statistical data from the Kampar Regency (2020-2023), relevant scientific publications, and policy documents. The research implemented methodological triangulation to ensure data validity and reliability by combining multiple data sources and collection methods (Flick, 2018).

SWOT analysis*.* The SWOT analysis was conducted following the framework developed by Helms and Nixon (2010). This process involved the preparation of Internal Factor Analysis Summary (IFAS) and External Factor Analysis Summary (EFAS) matrices, presented in Table 1 and Table 2, respectively, to assess the weight (w_i) and rating (r_i) of each factor. Weight determination was carried out through discussions with stakeholders and analysis of relevant literature, while ratings were assigned based on surveys of industry participants. The identification of SWOT factors utilized a multi-stage process. Initial factors were compiled through a thorough literature review and preliminary field observations. These factors were then refined through focus group discussions with industry stakeholders, including production unit owners, workers, and local fisheries officials. The validation process included iterative consultations with food industry specialists who assessed the relevance and significance of each factor. Ultimately, the process identified eight key factors within each SWOT quadrant, highlighting the most impactful elements based on their assessment and frequency of mention during stakeholder discussions. This number achieved data saturation, indicating that any additional factors would demonstrate redundancy or minimal influence on the overall analysis. The selection criteria prioritized factors that significantly affect industry operations, development potential, and sustainability, as confirmed by stakeholder consensus and expert validation.

The total scores for internal (S_I) and external (S_E) factors were calculated using the following equations:

For internal factors:

$$S_I = \sum (w_i \times r_i)$$

For external factors:

$$S_E = \sum (w_i \times r_i)$$

Where:

- S_I = Total score of internal factors
- S_E = Total score of external factors
- w_i = Weight of the iii-th factor (0 ≤ w_i ≤ 1, with $\sum w_i$ =1)
- r_i = Rating of the *i*-th factor (on a scale of 1 to 4)

Table 1

IFAS (Internal Factor Analysis Summary) matrix

Internal Factors	*Weight*	*Rating*	*Score*
Strengths			
1. Abundant and high-quality smoked pangasius production	0.10	4	0.40
2. Koto Mesjid Village known as "Pangasius Village"	0.05	3	0.15
3. Pangasius has rapid growth and thick meat	0.08	4	0.32
4. High economic value of pangasius	0.07	3	0.21
5. Increasing market demand, both domestic and export	0.10	4	0.40
6. Significant contribution to local community income	0.05	3	0.15
7. Availability of pangasius raw materials from local cultivation	0.08	4	0.32
8. Community expertise in smoked pangasius processing	0.07	3	0.21
Total Strengths			2.16
Weaknesses			
1. Processing still uses traditional methods	0.05	2	0.10
2. Lack of sanitation and hygiene standards application as per GMP	0.07	1	0.07
3. Suboptimal waste management from processing	0.08	1	0.08
4. Limited access to capital and modern technology	0.05	2	0.10
5. Lack of product diversification	0.04	2	0.08
6. Minimal education and training on good processing practices	0.04	2	0.08
7. Simple product packaging (using used cardboard)	0.03	2	0.06
8. Dependence on hardwood supply for the smoking process	0.04	1	0.04
Total Weaknesses			0.61
Total IFAS	1.00		2.77

The results of the IFAS analysis reveal a total score of 2.77, indicating a relatively solid internal position for the industry. The primary strengths lie in the abundant and high-quality production (score of 0.40) and the increasing market demand (score of 0.40). The most significant weaknesses identified are suboptimal waste management practices (score of 0.08) and the lack of application of sanitation and hygiene standards (score of 0.07).

Table 2

EFAS (External Factor Analysis Summary) matrix

External Factors	*Weight*	*Rating*	*Score*
Opportunities			
1. Potential for broader market development	0.10	4	0.40
2. Opportunity to increase product value through diversification	0.08	3	0.24
3. Possibility of implementing more modern and efficient processing technology	0.07	3	0.21
4. Potential for developing ecotourism based on the fish processing industry	0.05	2	0.10
5. Opportunity for collaboration with research institutions for product innovation	0.06	3	0.18
6. Potential for developing environmentally friendly waste management systems	0.08	4	0.32
7. Opportunity to obtain product certifications (e.g., halal, HACCP)	0.07	3	0.21
8. Potential for developing alternative energy for the smoking process	0.06	3	0.18
Total Opportunities			1.84
Threats			
1. Risk of environmental pollution due to poorly managed waste	0.09	1	0.09
2. Threat to workers' health due to long-term smoke exposure	0.07	1	0.07
3. Fluctuation in pangasius raw material prices	0.05	2	0.10
4. Competition from smoked fish producers in other regions	0.05	2	0.10
5. Changes in consumer preferences for processed fish products	0.04	2	0.08
6. Potential depletion of wood resources for smoking	0.06	1	0.06
7. Fire risk in the smoking process	0.04	1	0.04
8. Changes in regulations related to food safety and environmental standards	0.03	2	0.06
Total Threats			0.60
Total EFAS	1.00		2.44

The results of the EFAS analysis reveal a total score of 2.44, indicating that the industry responds to external factors slightly above average. The main opportunities identified are the expansion into broader markets (score of 0.40) and the potential for developing environmentally friendly waste management systems (score of 0.32). The most significant threats are environmental pollution due to poorly managed waste (score of 0.09) and health risks to workers from long-term smoke exposure (score of 0.07). The combination of the IFAS and EFAS analysis results provides a comprehensive picture of the strategic position of the smoked pangasius processing industry. With a total IFAS score of 2.77 and an EFAS score of 2.44, the industry is strong enough to leverage its internal strengths while facing external challenges and capitalizing on existing opportunities.

HOR analysis. The House of Risk (HOR) analysis was conducted in two stages, adapting the model developed by Pujawan & Geraldin (2009). In the first stage, House of Risk 1 (HOR1), applied to the smoked pangasius processing industry at the PHP Center in Koto Mesjid Village, ten significant risk events (E1–E10) and ten risk agents (A1–A10) were identified.

Table 3

House of risk matrix 1 (HOR1)

Risk Event	*A1*	*A2*	*A3*	*A4*	*A5*	*A6*	*A7*	*A8*	*A9*	*A10*	*Severity*
E1	9	3	1	0	0	0	3	9	1	0	8
E2	9	9	0	3	0	3	3	9	3	0	7
E3	0	3	9	1	0	0	0	1	3	1	9
E4	0	1	0	9	3	0	0	1	3	0	8
E5	0	3	0	9	9	0	0	1	3	1	10
E6	0	0	0	0	0	9	0	0	1	0	7
E7	1	1	0	0	0	0	9	3	1	0	6
E8	3	3	1	1	0	1	3	9	1	0	8
E9	0	3	0	3	9	0	0	1	3	0	9
E10	0	1	0	1	0	0	0	0	1	9	7
Occurrence	8	9	7	6	5	6	7	8	7	6	
ARP	1320	1944	679	1404	975	552	861	2088	1155	492	

The House of Risk 1 (HOR1) analysis identifies critical risk events and agents in the smoked pangasius processing industry. The risk events encompass various operational and environmental aspects, including microbial contamination (E1), product quality degradation (E2), environmental pollution (E3), and fire risk (E5). Occupational health and safety issues, such as health problems due to smoke exposure (E4) and workplace accidents (E9), are also addressed. The identified risk agents comprise internal factors like lack of sanitation standards (A1), traditional processing methods (A2), and insufficient quality control (A8), as well as external factors such as limited access to capital (A9) and depletion of wood resources (A10). This comprehensive identification provides a solid foundation for further analysis and developing effective risk mitigation strategies in the smoked pangasius processing industry.

The Aggregate Risk Potential (ARP) for each risk agent j is calculated using the following equation:

$$ARP_j = O_j \times \sum (S_i \times R_{ij})$$

Where:
ARP_j = Aggregate Risk Potential of risk agent *j*
O_j = Probability of occurrence of risk agent *j*
S_i = Severity of impact if risk event *i* occurs
R_{ij} = Correlation between risk agent *j* and risk event i (scale of 0, 1, 3, or 9)

Based on the HOR1 analysis, we can focus on the top five risk agents with the highest ARP values and identify potential mitigation actions for each (Table 4).

Table 4

Priority risk agents and potential mitigation measures

Risk Agent	*ARP*	*Potential Mitigation Actions*
A8: Lack of quality control	2256	PA1: Implementation of quality management system (ISO 9001) PA2: Training and certification in Good Manufacturing Practices (GMP)
A2: Traditional processing methods	1701	PA3: Modernization of processing and smoking technology PA4: Training program on modern production technology
A1: Lack of sanitation and hygiene standards application	1656	PA5: Implementation of HACCP standards PA6: Improvement of sanitation and hygiene facilities
A4: Limited safe smoking technology	1218	PA7: Investment in modern and safe smoking technology PA8: Development of better ventilation systems
A7: Inadequate product packaging	1008	PA9: Development of better packaging designs PA10: Investment in modern packaging technology

We formulate risk mitigation strategies in the second stage of the House of Risk analysis, known as HOR2. The Total Effectiveness (T_{EK}) of each mitigation action k is calculated using the following equation:

$$TEk = \sum (E_{jk} \times ARP_j)$$

Where:
T_{EK} = Total effectiveness of mitigation action
E_{jk} = Effectiveness level of action k in reducing the probability of occurrence of risk agent
ARP_j = Aggregate Risk Potential of risk agent

To prioritize the mitigation actions, we calculate the Effectiveness to Difficulty Ratio (ETD_k):

$$ETD_k = \frac{TE_k}{D_k}$$

Where:
ETD_k = Effectiveness to Difficulty Ratio of mitigation action k
D_k = Difficulty level of implementing action k

This approach allows for a systematic evaluation of mitigation actions by considering their potential effectiveness in reducing risks and the practical challenges associated with their implementation. Higher ETD_k values indicate mitigation actions that offer more significant risk reduction relative to their implementation difficulty, helping prioritize the most efficient risk management strategies (Table 5).

Table 5

House of risk matrix 2 (HOR2)

Risk Agent	*ARP*	*PA1*	*PA2*	*PA3*	*PA4*	*PA5*	*PA6*	*PA7*	*PA8*	*PA9*	*PA10*
A8	2256	9	9	3	3	9	3	1	1	3	3
A2	1701	3	3	9	9	3	3	9	3	1	3
A1	1656	9	9	3	3	9	9	1	3	1	1
A4	1218	3	3	9	3	3	1	9	9	1	1
A7	1008	3	3	1	1	1	1	1	1	9	9
TEk		58644	58644	46710	40095	53244	37179	38475	29889	24300	28872
Dk		4	3	5	4	4	3	5	3	2	4
ETDk		14661	19548	9342	10024	13311	12393	7695	9963	12150	7218

Results. The SWOT Matrix (Table 6) was constructed based on the internal and external factor analyses of the smoked striped catfish processing industry at the PHP Center in Koto Mesjid Village. This matrix integrates the eight strengths, eight weaknesses, eight opportunities, and eight threats previously identified, resulting in 30 potential strategies divided into four categories: SO (Strengths-Opportunities), WO (Weaknesses-Opportunities), ST (Strengths-Threats), and WT (Weaknesses-Threats). The proactive nature of the SO strategies, such as market expansion (SO1) and new product development (SO2), is evident as they aim to leverage internal strengths to capitalize on external opportunities. Similarly, the WO strategies—for example, modernization of production processes (WO1) and implementation of quality management systems (WO2)—focus on improving weaknesses by taking advantage of existing opportunities. The SWOT Matrix provides a comprehensive framework for developing strategies to enhance the competitiveness and sustainability of the smoked striped catfish processing industry in Koto Mesjid Village.

Table 6

SWOT matrix that integrates the results of internal and external factor analysis to formulate potential strategies

	Strengths (S)	Weaknesses (W)
	1. Abundant and quality smoked catfish production 2. Known as "Patin Village" 3. Superior characteristics of catfish 4. High economic value of catfish 5. Increasing market demand 6. Significant contribution to the local economy 7. Availability of local raw materials 8. Community expertise in processing	1. Processing is still traditional 2. Lack of sanitation standards and GMP implementation 3. Waste management is not optimal 4. Limited access to capital and modern technology 5. Lack of product diversification 6. Limited education and training 7. Simple product packaging 8. Dependence on hardwood for smoking
Opportunities (O)	*SO Strategies*	*WO Strategies*
1. Potential for broader market development	SO1: Market expansion by leveraging "Patin Village" reputation and product quality (S1, S2, S5, O1)	WO1: Modernization of production processes through the adoption of new technology (W1, W4, O3)
2. Added value improvement through diversification	SO2: Development of new products based on catfish for diversification (S3, S4, O2)	WO2: Implementation of quality management and food safety systems for certification (W2, W6, O7)
3. Application of modern technology	SO3: Increasing production capacity using modern technology (S1, S7, O3)	WO3: Development of an integrated waste management system (W3, O6)
4. Development of ecotourism	SO4: Development of an ecotourism program based on the catfish industry (S2, S6, O4)	WO4: Training and HR development to improve production quality (W6, O3, O7)
5. Collaboration with research institutions	SO5: Research collaboration for product and process innovation (S3, S8, O5)	WO5: Collaboration with designers for product packaging improvement (W7, O2)
6. Development of waste management systems	SO6: Implementation of environmentally friendly waste management systems (S1, O6)	WO6: Product diversification through research and development (W5, O2, O5)
7. Product certification	SO7: Obtaining certification to enhance product value (S1, S4, O7)	WO7: Development of alternative smoking methods (W8, O8)
8. Development of alternative energy	SO8: Adoption of alternative energy for production efficiency (S8, O8)	
Threats (T)	*ST Strategies*	*WT Strategies*
1. Risk of environmental pollution	ST1: Implementation of clean production practices (S1, S8, T1)	WT1: Development of an environmental management system (W3, T1)
2. Worker health threats	ST2: Improving occupational safety and health systems (S8, T2)	WT2: Adoption of safer smoking technologies (W1, W8, T2)
3. Fluctuations in raw material prices	ST3: Development of contract systems with local suppliers (S7, T3)	WT3: Diversification of raw material sources (W4, T3)
4. Competition from other regions	ST4: Strengthening the "Patin Village" branding (S2, S4, T4)	WT4: Increasing production efficiency to reduce costs (W1, W4, T4)
5. Changing consumer preferences	ST5: Product innovation in line with market trends (S3, S8, T5)	WT5: Development of new healthy and practical product lines (W5, T5)
6. Depletion of wood resources	ST6: Efficiency in wood used for the smoking process (S8, T6)	WT6: Research and development of alternative smoking methods (W8, T6)
7. Fire risk	ST7: Improving safety systems and fire prevention (S8, T7)	WT7: Modernization of production facilities with integrated safety systems (W1, W4, T7)
8. Regulatory changes	ST8: Proactively adopting food safety and environmental standards (S1, S4, T8)	WT8: Increasing compliance with regulations through training and certification (W2, W6, T8)

The SWOT Quadrant Diagram (Figure 2a) illustrates the strategic position of the striped smoked catfish processing industry in Quadrant I, with coordinates (1.55, and 1.24). This placement indicates a highly favorable situation characterized by dominant internal strengths and significant external opportunities, supporting the implementation of aggressive or growth-oriented strategies. Meanwhile, the SWOT Radar Graph (Figure 2b) visualizes the relative strength of each SWOT component. The graph displays an unbalanced polygon shape with more extensive areas in the Strengths (2.16) and Opportunities (1.84) quadrants, confirming the dominance of internal strengths and external opportunities. Conversely, the Weaknesses (0.61) and Threats (0.60) quadrants show relatively more minor values. Both visualizations complement and reinforce the SWOT analysis results, clearly depicting the industry's strategic position conducive to expansion, product diversification, and innovation. This visual interpretation aligns with the strategies formulated in the SWOT Matrix (Table 6), particularly the SO (Strengths-Opportunities) strategies that leverage strengths to capitalize on existing opportunities.

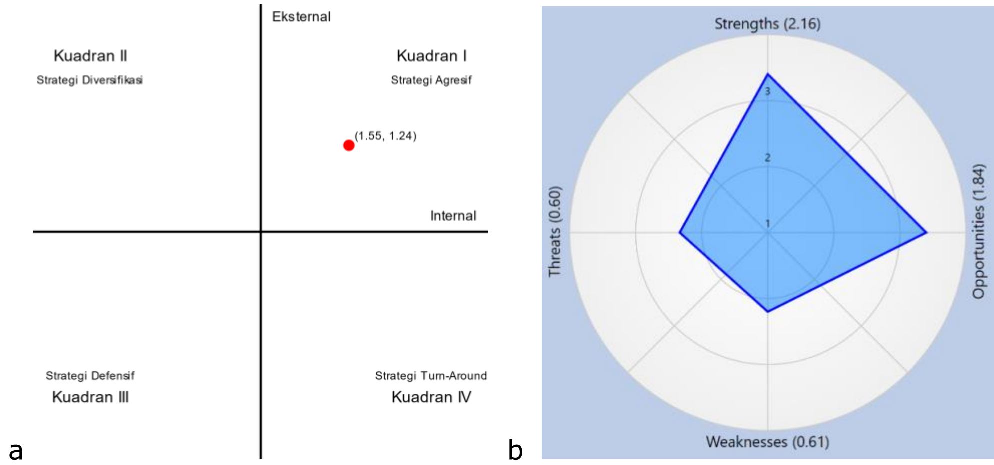

Figure 2. Visualization of SWOT Analysis for the smoked striped catfish processing Industry in the PHP Center of Koto Mesjid Village: (a) SWOT Quadrant Diagram showing the strategic position in Quadrant I; (b) SWOT Radar Graph displaying the value distribution of SWOT components. Both graphs reveal the potential for expansive and innovative strategies while emphasizing the importance of mitigating weaknesses and anticipating threats to ensure sustainable growth.

Based on the Aggregate Risk Potential (ARP) calculations, the risk agents have been ranked from highest to lowest to determine handling priorities. This ranking allows for identifying the most critical risk agents that require immediate attention in the risk mitigation process. The visualization of these risk agent priorities is presented in the Pareto Diagram (Figure 3), which highlights the risk agents that contribute most significantly to the overall risk profile of the industry.

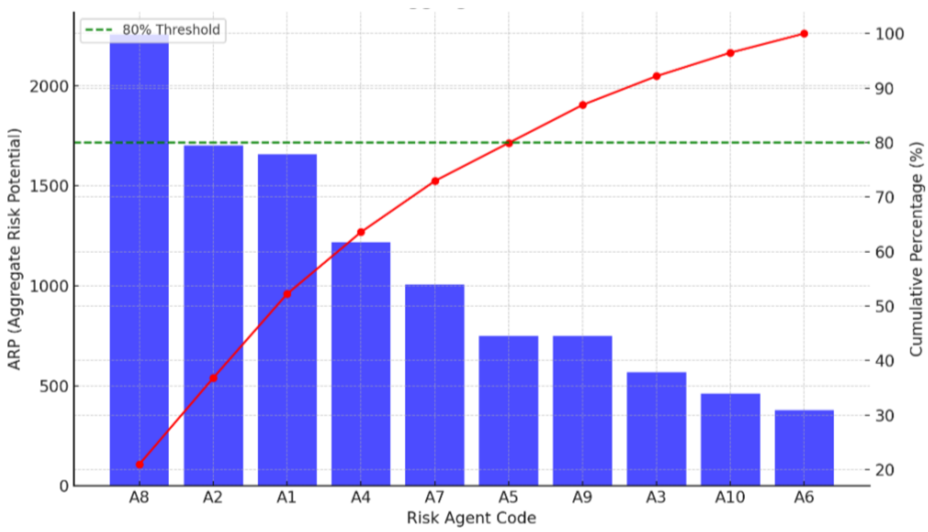

Figure 3. The Pareto chart displays the priority of risk agents based on their Aggregate Risk Potential (ARP). The top four risk agents (A8, A2, A1, A4) contribute to over 80% of the total risk, indicating they require immediate attention for mitigation.

The Pareto Diagram demonstrates that addressing the top risk agents can significantly impact overall risk reduction in the smoked striped catfish processing industry at the PHP Center in Koto Mesjid Village. By applying the Pareto principle, mitigating approximately 20–30% of the top risk agents—in this case, the first three to four—can alleviate most of the total risks faced by the industry. A risk relationship matrix is visualized through a heatmap diagram (Figure 4) to examine the relationships between risk events and agents in greater detail. This visualization displays the intensity of relationships between risk events and agents using color gradients, complementing the priority information obtained from the Pareto Diagram. The heatmap enables the identification of critical risk patterns and facilitates the development of targeted mitigation strategies.

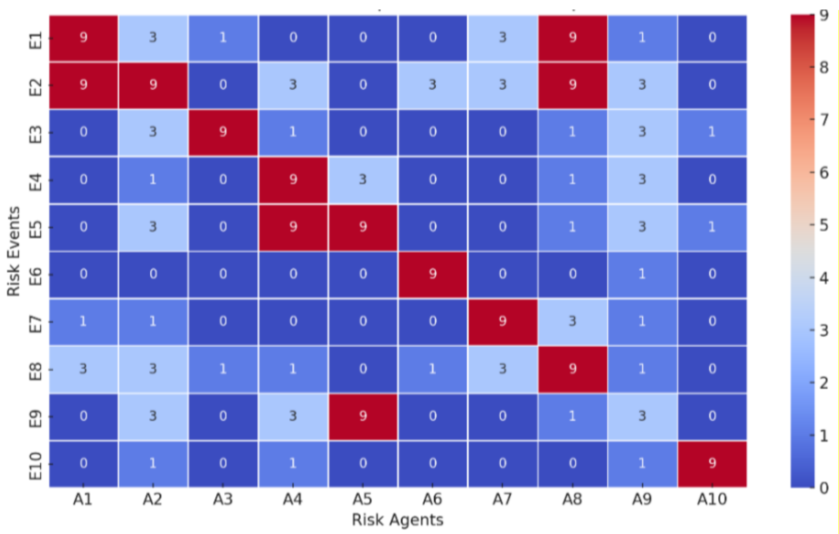

Figure 4. Heat Map of the Risk Relationship Matrix. The color gradient represents the strength of the relationship between risk events (E1 to E10) and risk agents (A1 to A10), with darker colors indicating stronger relationships (higher values).

The heatmap diagram illustrates the correlations between ten risk events (E1–E10) and ten risk agents (A1–A10) using a color scale ranging from blue (low correlation) to red (high correlation), with numerical values indicating specific correlation levels (0, 1, 3, 9). From this visualization, several significant patterns emerge. Risk agent A8 (lack of quality control) shows a high correlation (value of 9) with multiple risk events, especially

E1 (microbial contamination), E2 (product quality degradation), and E8 (customer complaints), indicating its crucial role in various aspects of production risk. Similarly, A1 (lack of sanitation and hygiene standards implementation) and A2 (traditional processing methods) also exhibit high correlations with several risk events, emphasizing the importance of sanitation practices and process modernization. Some risk agents, such as A6 (dependence on a single type of raw material) and A10 (depletion of local wood resources), display high correlations only with specific risk events, signifying a more focused influence. The diagram also reveals that certain risk events, like E3 (environmental pollution) and E5 (fire during the smoking process), have high correlations with specific risk agents, highlighting areas that require special attention in risk mitigation strategies. This visualization provides a deeper understanding of the complexity and interconnectedness of risks within the industry, aiding in formulating more targeted and effective mitigation strategies.

Risk mitigation action priorities have been identified using the Effectiveness to Difficulty Ratio (ETD_k) values. Figure 5 presents a graphical visualization of these priorities, helping to comprehend the relative importance of each proposed mitigation action. The graph clearly illustrates how various mitigation actions compare effectiveness and ease of implementation, providing valuable guidance for decision-makers in the smoked catfish processing industry at the PHP Center of Koto Mesjid Village.

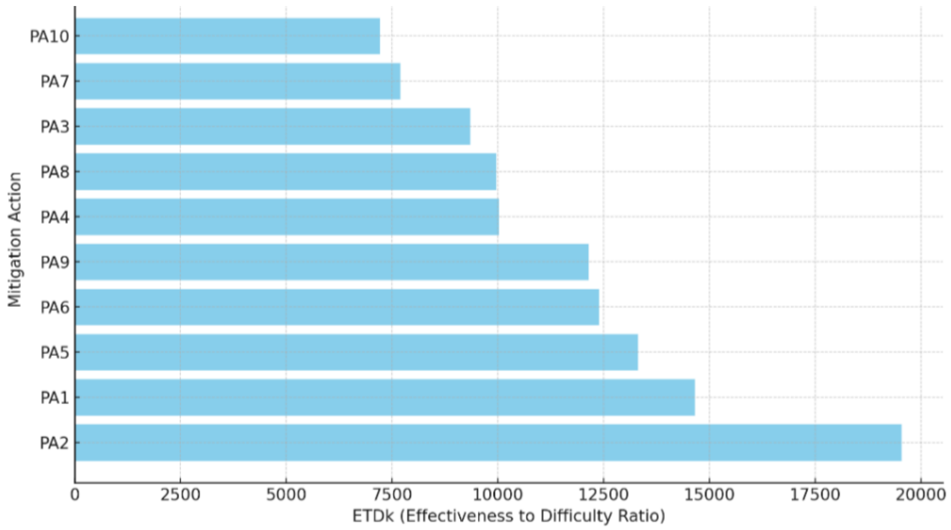

Figure 5. The bar chart above displays the prioritization of mitigation actions based on their Effectiveness to Difficulty Ratio (ETDk). Actions with higher ETDk values, such as PA2: Training and Certification in Good Manufacturing Practices (GMP) and PA1: Implementation of the quality management system (ISO 9001), should be prioritized as these offer the most significant effectiveness relative to their difficulty. Lower ETDk values indicate actions that may be less effective or more difficult to implement, such as PA10: Investment in modern packaging technology and PA7: Investment in modern and safe smoking technology.

The Prioritization of Mitigation Actions Diagram illustrates the order of priority for implementing mitigation strategies based on their Effectiveness to Difficulty Ratio (ETD_k) values. Higher ETD_k values indicate that mitigation action is more effective relative to its difficulty level, making it a top priority for implementation. In this diagram, PA2: Training and Certification in Good Manufacturing Practices (GMP) has the highest ETD_k value, followed by PA1: Implementation of a quality management system (ISO 9001) and PA5: Implementation of Hazard Analysis and Critical Control Points (HACCP) standards. These three actions should be the primary focus for risk reduction in the smoked catfish processing industry. Other mitigation actions, such as PA6: Improvement of sanitation and hygiene facilities and PA9: Development of better packaging design, are also significant but have a lower priority than actions with higher ETD_k values. Mitigation actions with the lowest ETD_k values, such as PA10: Investment in modern packaging technology and PA7: Investment in modern and safe smoking technology, require further evaluation. Although effective, these actions may be more difficult or costly to implement than other options. This prioritization helps decision-makers focus on mitigation strategies that offer the most significant risk reduction benefits relative to their implementation challenges, optimizing resource allocation and enhancing the overall sustainability of the smoked striped catfish processing industry at the PHP Center in Koto Mesjid Village.

Discussion. The SWOT and HOR analyses for the smoked striped catfish processing industry at the PHP Center in Koto Mesjid Village reveal several significant findings that warrant comprehensive discussion. The industry's placement in Quadrant I of the SWOT diagram indicates a highly favorable situation characterized by dominant internal strengths and substantial external opportunities. According to Helms and Nixon (2010), organizations in this position should implement aggressive strategies to maximize growth. However, David & David (2017) caution that long-term success depends on maintaining competitive advantage through continuous innovation.

The SWOT radar graph highlights extensive strengths and opportunities but points to weaknesses that must be addressed. Focusing on increasing production capacity and modernizing processes (strategies SO3 and WO1) aligns with Trienekens' (2011) recommendations on the importance of technological upgrades in agro-industry value chains in developing countries. Implementing quality management systems (strategy WO2) is also crucial, given the significance of food safety standards in the global food industry (Yadav et al 2021).

The Pareto diagram and heatmap reveal that lack of quality control (A8) and reliance on traditional processing methods (A2) are the main risk agents. These findings corroborate Olson & Wu's (2020) argument that risk management in food supply chains should prioritize product safety and quality. Mitigation strategies such as implementing Good Manufacturing Practices (GMP) and ISO 9001 standards align with FAO/WHO (2020) recommendations on strengthening food safety systems in small and medium-scale industries.

New product development and diversification strategies are essential for addressing changing consumer preferences. Nosratabadi et al. (2020) emphasize the importance of product innovation in creating sustainable business models in the agri-food sector. Collaboration with research institutions can accelerate the innovation process, as Carayannis et al (2021) argued in the quadruple helix innovation model. Risk agents related to waste management and wood usage indicate an urgent need to adopt more environmentally friendly production practices. Strategies focusing on clean production and environmental management align with the circular economy concept, which is increasingly important in the food industry (Jurgilevich et al 2016). Developing alternative energy sources for smoking processes is also crucial for long-term sustainability, given the growing global emphasis on renewable resource utilization (IRENA 2021).

The high priority placed on GMP training underscores the importance of human resource capacity development. Vos et al (2021) argue that investment in training and education is a critical factor in enhancing the competitiveness of small and medium-scale food industries. Emphasizing training and human resource development also supports the concept of organizational learning, which Senge (2014) highlighted as the foundation for adaptability and sustainable innovation. The striped catfish processing industry in Koto Mesjid Village significantly contributes to the local economy and offers potential for ecotourism development, presenting opportunities for deeper integration with regional development initiatives. This aligns with the concept of local economic development advocated by Pike et al (2017), which emphasizes optimizing local resources for inclusive economic growth. By developing striped catfish industry-based ecotourism programs, the region can leverage its unique resources to create sustainable economic opportunities that benefit the local community while preserving the area's ecological balance.

Overall, the analysis indicates that the smoked striped catfish processing industry at the PHP Center in Koto Mesjid Village has excellent potential for growth and contribution to local economic development. Realizing this potential depends on implementing appropriate strategies to overcome internal weaknesses, mitigate risks, and capitalize on market opportunities optimally. A holistic approach integrating increased production capacity, product innovation, risk management, and environmental sustainability will be critical to the industry's long-term success. Proposed strategies should be implemented gradually and systematically, considering available resources and the continuously changing market dynamics.

Conclusions. The SWOT and HOR analyses reveal that the smoked striped catfish processing industry at the PHP Center in Koto Mesjid Village holds a solid strategic position with significant growth potential. The industry benefits from dominant internal strengths, such as high-quality production and rising market demand, along with promising external opportunities for expansion. To fully realize this potential, addressing existing weaknesses and risks, particularly those related to traditional processing methods, quality management, and environmental sustainability, is crucial. Implementing quality management systems like ISO 9001, adopting good manufacturing practices (GMP), and modernizing production technology are essential steps forward. Enhancing human resource capacities through training and certification will further bolster the industry's competitiveness. Integrating the industry with the local economy through initiatives like ecotourism can add significant value and promote sustainable development. By strategically addressing internal and external challenges while capitalizing on market opportunities, the industry is well-positioned for sustainable growth. Long-term success will depend on its ability to adapt to market changes, improve operational efficiency, maintain product quality, and uphold environmental stewardship.

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