Quality Control Analysis of Export-Grade Barramundi (*Lates calcarifer*) Fillet Using Statistical Process Control and Failure Mode and Effect Analysis

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Abstract**—** Ensuring consistent product quality in export-oriented seafood processing is essential to comply with international standards and maintain market competitiveness. This study evaluates the quality control performance of export-grade barramundi (*Lates calcarifer*) fillet production using an integrated approach combining Statistical Process Control (SPC) and Failure Mode and Effect Analysis (FMEA). The research was conducted over a seven-month period (August 2025-February 2026) at a seafood processing company in Denpasar, Bali, Indonesia. SPC tools, including check sheets, Pareto diagrams, p-control charts, and fishbone diagrams, were applied to monitor process stability and identify dominant defect types. The results indicated four primary defects: improper fillet cutting (42.65%), vacuum leakage (35.29%), labeling errors (10.29%), and residual scales (11.76%). The p-chart analysis showed that the process remained statistically under control, although defect proportions increased during peak production in December. Pareto analysis revealed that improper cutting and vacuum leakage contributed nearly 78% of total defects, highlighting critical control points in processing and packaging stages. FMEA identified improper fillet cutting as the highest-risk failure mode, with an RPN of 168, followed by residual scales (RPN = 90) and vacuum leakage (RPN = 72). The integration of SPC and FMEA effectively distinguished statistically stable processes from operational risks requiring targeted corrective actions, thereby supporting better decision-making and strengthening quality assurance in seafood fillet processing.

Keywords— Barramundi Fillet, Failure Mode and Effect Analysis, Seafood Processing, Quality Control, Statistical Process Control

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I. INTRODUCTION

Ensuring consistent product quality in seafood processing is essential to comply with stringent international export standards and to minimize economic losses resulting from product rejection, rework, or reduced shelf life. Export-oriented seafood industries operate under strict regulatory frameworks that demand traceability, hygiene control, temperature management, and product uniformity [1]. In fillet processing, quality deviations may arise from raw material variability, manual handling, equipment performance, or packaging integrity, all of which can directly influence product safety and market acceptance. Therefore, the implementation of systematic and data-driven quality control approaches is critical to maintaining competitiveness and sustaining consumer confidence in global seafood markets.

In recent decades, food processing industries have increasingly adopted quantitative quality management methods to monitor process stability and detect variations at early stages [2]. Statistical Process Control (SPC) is one of the most widely applied methodologies for monitoring production performance using statistical tools such as control charts, Pareto diagrams, and cause-and-effect analysis [3]. By distinguishing between common-cause variation and special-cause variation, SPC enables manufacturers to evaluate whether a process operates within statistically acceptable limits [4]. Previous research on frozen seafood production has demonstrated that SPC tools effectively identify dominant defect types and highlight critical stages contributing to quality deviations [5]. Sufa [6] reported that SPC successfully monitored the quality of worker performances in fish paste industries. Meanhwile, Prata et al., [7] found that SPC validates HACCP plans by accurately predicting and controlling product defect risks. These studies confirm that statistical monitoring supports continuous improvement by providing objective evidence of process behavior over time.

However, while SPC is effective in detecting process instability, it does not inherently prioritize the relative risk associated with different failure modes. A process may appear statistically controlled while still containing high-risk defects that require urgent attention. To address this limitation, Failure Mode and Effect Analysis (FMEA) offers a structured framework for identifying potential failure modes, analyzing their

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causes and consequences, and quantifying their risk using the Risk Priority Number (RPN) [8]. FMEA evaluates each failure mode based on severity, occurrence, and detectability, allowing organizations to rank risks and allocate corrective resources efficiently [3], [9]. Wiśniewska et al., [10] mentioned that the seafood organization successfully adopted a detailed EFMEA approach to track and control its ecological footprint, pinpointing refrigeration and cargo logistics as its primary environmental threats despite early setbacks with data and expertise. In industrial quality research, combined approaches using SPC and FMEA have been documented across manufacturing sectors to improve process reliability and reduce defect rates. For example, studies in garment, panada tore, and edamame demonstrate that integrating SPC for statistical monitoring with FMEA for risk prioritization effectively highlights critical process steps requiring corrective action [8], [11], [12], [13]. Although these studies are not specific to seafood, they underline the general effectiveness of combining SPC and FMEA to improve quality outcomes in complex production environments where variation and multiple potential failure points coexist. However, applications of integrated SPC-FMEA specifically in seafood fillet processing remain limited in formal literature. While quality control research exists using SPC tools only for frozen pocket tuna processes [5], canned fish [14], and koi fish production [15], comprehensive studies that apply both SPC and FMEA to fillet production systems are scarce.

Barramundi (*Lates calcarifer*) fillet production involves multiple manual and mechanical stages, including receiving, scaling, filleting, trimming, vacuum packaging, labeling, and cold storage. Each stage presents potential failure points that may compromise product appearance, safety, or export compliance. Quality deviations may result from operator skill variability, knife sharpness, sealing temperature instability, labeling errors, or insufficient inspection procedures. Considering these complexities, relying solely on statistical monitoring may not sufficiently address risk prioritization. Therefore, the adoption of an integrated SPC-FMEA framework offers a comprehensive approach that combines quantitative process control with structured risk assessment. This dual methodology not only supports proactive defect prevention but also contributes to strengthening scientific understanding and practical implementation of quality assurance systems in seafood processing industries.

II. Method

A. Study Site and Research Design

This study was conducted at a seafood processing company located in Denpasar, Bali, Indonesia, engaged in the production of export-grade barramundi (*Lates calcarifer*) fillets. Data was collected during routine production activities over a seven-month observation period (August 2025-February 2026). The study employed a quantitative descriptive approach integrating Statistical Process Control (SPC) and Failure Mode and Effect Analysis (FMEA) to evaluate process stability and prioritize quality risks [8]. The research design followed an industrial case study framework, where real production data were analyzed to assess defect patterns and process variation. The integration of SPC and FMEA is widely recognized in quality engineering for systematic defect identification and risk prioritization [16]. SPC is used to monitor process behavior statistically, while FMEA identifies and ranks potential failure modes based on risk severity.

B. Statistical Process Control (SPC)

SPC was implemented to evaluate the stability of the barramundi fillet production process. SPC analysis included the use of check sheets, Pareto diagrams, p-control charts, and fishbone diagrams, following the previous study by Alifka et al. [8].

a. Check Sheet

A check sheet was used to systematically record daily production results and defect types during the seven-month observation period. The check sheet served as the primary data source for subsequent statistical analysis.

b. Pareto Diagram

A Pareto diagram was constructed to classify and rank defect types according to their frequency. The total number of defects for each category was calculated and arranged from the highest to the lowest frequency. Cumulative percentages were then determined to identify dominant defect contributors based on the Pareto principle.

c. P-Control Chart (p-Chart)

Because the quality characteristics were attribute-based (defective vs. non-defective products) and daily production volumes varied, a p-control chart was used. The p-chart monitors the proportion of defective units in each subgroup. The proportion of defective units for each observation period was calculated followed Eq.1.

$$p_i = \frac{np_i}{n_i} \quad (1)$$

where pi is the proportion of defects in the i-th subgroup, npi is the number of defective units in the i-th subgroup, and ni is the total number of inspected units in the same subgroup.

The overall average proportion defective (center line/ CL) was calculated followed Eq. 2.

$$CL = \bar{p} = \frac{\sum np_i}{\sum n_i} \quad (2)$$

where CL or $\bar{p}$ is the center line, $\sum np_i$ is the total number of damaged items, and $\sum n_i$ is the total number of items inspected.

The upper control limit (UCL) for the p-chart was determined using Eq.3.

$$UCL = \bar{p} + 3\left(\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}\right) \quad (3)$$

TABLE 1.
SEVERITY, OCCURRENCE, AND DETECTION RATING SCALE

Severity		
Score	**Criteria Description**	**Impact on Product**
1	No significant effect	No impact on quality
2–3	Minor deviation	Slight quality deviation, still acceptable
4–6	Moderate effect	Noticeable quality reduction requiring rework
7–8	High impact	Product may not meet export standards
9–10	Critical impact	Product rejection or serious compliance issue
Occurrence		
Score	**Frequency Description**	**Probability Level**
1	Rare occurrence	Very unlikely
2–3	Low frequency	Occasional
4–6	Moderate frequency	Repeated occurrence
7–8	High frequency	Frequent occurrence
9–10	Very high frequency	Almost inevitable
Detection		
Score	**Detection Capability**	**Detection Likelihood**
1	Almost certain detection	Defects always detected
2–3	High detection probability	Easily detected during inspection
4–6	Moderate detection	Sometimes detected
7–8	Low detection probability	Difficult to detect
9–10	Very low detection probability	Almost impossible to detect

The lower control limit (LCL) was calculated using Eq.4.

$$LCL = \bar{p} - 3\left(\sqrt{\frac{\bar{p}(1-\bar{p})}{n}}\right) \tag{4}$$

Where $\bar{p}$ is the center line / average damage, and n is the average check quantity.

d. Fishbone Diagram

To identify potential root causes of defects, cause-and-effect (fishbone) diagrams were developed. Causes were grouped under standard categories, including Man (operator factors), Machine (equipment conditions), Method (procedural consistency), and Material. This qualitative tool was used to systematically organize possible contributing factors identified through observation and interviews.

C. Failure Mode and Effect Analysis (FMEA)

FMEA was applied to systematically identify, evaluate, and prioritize potential failure modes in the barramundi fillet production process. The method followed a structured procedure involving identification of potential failure modes, determination of their effects, analysis of possible causes, and evaluation of existing controls. Three main indicators were used to assess each failure mode including severity (S), occurrence (O), and detection (D) as shown in Table 1.

The Risk Priority Number (RPN) was calculated for each identified failure mode using Eq. 5.

$$RPN = SxOxD \tag{5}$$

where RPN is risk priority number, S is the severity, O is the occurrence, and D is the detection.

III. RESULTS AND DISCUSSION

The production flow of barramundi (*Lates calcarifer*) fillet begins with the reception of fresh raw materials, which constitutes a critical control stage in maintaining product quality, as shown in Figure 1. Upon arrival at the processing facility, fish are unloaded carefully and transferred to the receiving area for inspection. Each batch is documented, including supplier identity, date of receipt, grade, and internal arrival code indicating harvest origin and reception date. This stage ensures full traceability and quality verification of incoming raw materials before processing. Proper documentation of supplier, date, grade, and origin supports food safety compliance, audit requirements, and effective production control [17]. Quality evaluation involves temperature measurement using a calibrated digital probe thermometer, ensuring that fish core temperature remains within the company standard of 0-4.4 °C and preferably below 4 °C to prevent rapid quality deterioration [18]. Organoleptic assessment covering odor, texture, and appearance is conducted using a standardized score sheet by Quality Control personnel. This stage is to ensure that only fish meeting predefined freshness and quality standards are accepted for processing, thereby preventing substandard raw materials from entering the production line [19].

Following acceptance, the fish undergo sorting to standardize raw materials based on size, type, freshness, and overall quality. This step ensures uniformity and minimizes the risk of processing substandard materials. Because barramundi is generally harvested upon customer order and delivered immediately to the facility, freshness is typically well maintained. After sorting, the fish are subjected to sizing and temporary labeling. Individual fish are weighed rapidly and hygienically, with central temperature maintained at a maximum of 5 °C. Fish weighing 400-800 g are categorized for export markets, while those weighing 200-400 g are allocated for local distribution. Each size category is grouped separately and assigned a temporary identification to maintain traceability throughout processing.

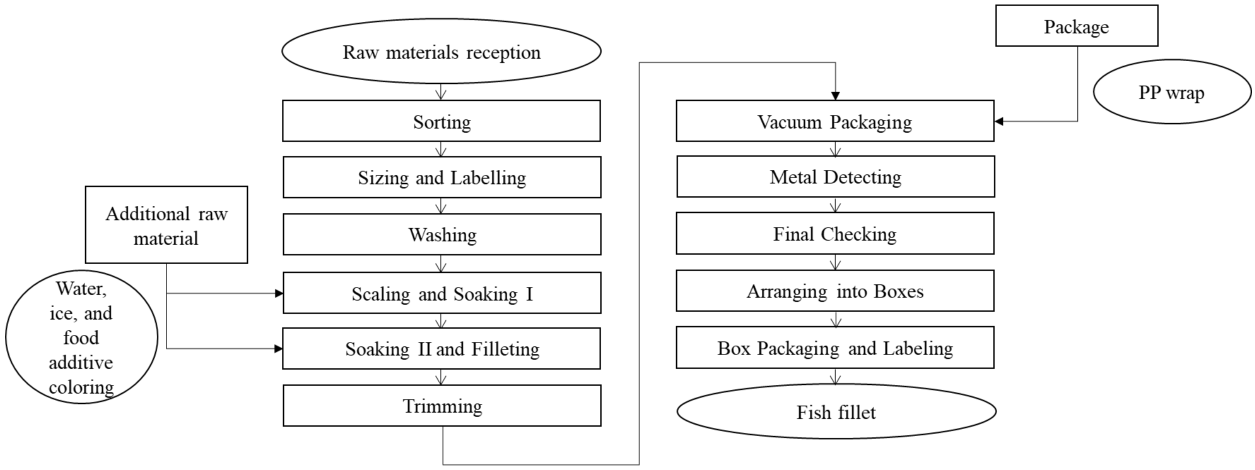

Figure 1. Barramundi fillet production process flow

The subsequent stages involve washing, scaling, soaking, and filleting under strict sanitation and cold-chain control. Washing is performed using running water to remove blood, mucus, and surface contaminants. Scaling is carried out manually with stainless steel descaling tools on stainless steel worktables equipped with continuous water flow to enhance cleanliness and reduce contamination risk. These stages are to remove physical contaminants and surface impurities under hygienic conditions while maintaining the cold chain, thereby preserving product safety and quality prior to further processing [20]. After scaling, fish are immersed in chilled water with crushed ice at 0-2 °C to prevent temperature increase and maintain freshness [21]. A second soaking step in the processing room utilizes a mixture of water, ice, and food-grade additives to preserve color and physical quality. Filleting is conducted manually using sharp stainless-steel knives, separating flesh from bone with precise horizontal cuts along the backbone. Sanitary handling is emphasized, with regular cleaning of work surfaces and proper segregation of processing waste to prevent cross-contamination.

After filleting, trimming is performed to remove red muscle tissue, residual membranes, and uneven edges to meet export specifications, producing uniform white fillets preferred by buyers. The trimmed fillets are then vacuum-packed using polypropylene (PP) plastic with controlled pressure below 1 atm to remove oxygen and extend shelf life [22]. Each package undergoes metal detection to ensure the absence of metallic contaminants originating from equipment or handling tools. The products are subsequently stored in a chiller at 2-4 °C to restore and maintain low product temperature before final inspection. During the final checking stage, packages are examined for leakage, labeling accuracy, physical appearance, and compliance with buyer requirements. Approved products are arranged in styrofoam boxes with ice gel, labeled according to regulatory standards, sealed securely, and prepared for distribution to domestic markets or export destinations, including Australia, the United States, and other Asian countries.

A. SPC Implementation

a. Check Sheet

Based on the production data from August 2025 to February 2026 (Table 2), four principal defect types were consistently identified in the barramundi fillet processing line, namely improper fillet cutting, vacuum leakage, labeling errors, and residual scales inside vacuum-packaged products. These defects can be grouped into two major categories: (1) processing-related physical defects (improper fillet cutting and residual scales) and (2) packaging-related defects (vacuum leakage and labeling errors). Throughout the seven-month observation period, improper fillet cutting and vacuum leakage were the most recurrent defect types, indicating that both manual cutting operations and vacuum sealing performance represent critical control points in the production system.

The monthly trend shows a steady increase in production volume from August (5,820 kg raw material) to November (7,200 kg), followed by a sharp peak in December (12,300 kg), and a subsequent decline in January and February. The total number of defects followed a similar pattern, rising from 6 cases (0.20%) in August to 11 cases (0.30%) in November, and reaching the highest level in December with 21 cases (0.34%). After December, defects decreased to 9 cases (0.21%) in January and 6 cases (0.15%) in February. This proportional increase during higher production months suggests that defect occurrence is influenced by production intensity.

From August to October, improper fillet cutting was the most frequent defect (3-4 cases per month), indicating variability in manual filleting performance. During these months, vacuum leakage remained secondary but showed a gradual increase. In November and especially December, vacuum leakage became more prominent (3 cases in November and 9 cases in December), representing the dominant contributor to the overall defect spike in December. This shift suggests that packaging performance becomes more vulnerable under high production loads, likely due to prolonged machine operation, increased sealing cycles, or insufficient preventive maintenance during peak demand.

(a) (b) (c) (d)

Figure 2. Types of product defects. (a) improper fillet cutting; (b) vacuum leakage; (c) labelling error; (d) residual scales

TABLE 2.
PRODUCTION AND DEFECT DATA

Month	Total Raw Material (kg)	Total Process Yield (kg)	Total Defects (pcs)	% Defects	Dominant Defect Types			
					Improper Fillet	Vacuum Leakage	Labelling Error	Residual Scales
Aug-25	5,820	2,940	6	0.20%	3	2	0	1
Sep-25	6,150	3,120	7	0.22%	4	2	1	0
Oct-25	6,480	3,290	8	0.24%	4	3	0	1
Nov-25	7,200	3,650	11	0.30%	4	3	4	0
Dec-25	12,300	6,180	21	0.34%	7	9	2	3
Jan-26	8,450	4,220	9	0.21%	4	3	0	2
Feb-26	7,900	3,980	6	0.15%	3	2	0	1

Consequently, this vulnerability increases the risk of widespread seal failures, potentially leading to costly product recalls and significant waste due to contamination or spoilage during distribution [23]. Meanwhile, vacuum leakage defects occur when packaging seals are incomplete or inconsistent, allowing air infiltration and potentially reducing product shelf life. The sharp increase in leakage cases during December indicates possible strain on sealing equipment performance, temperature stability, or pressure consistency under intensive operation. In contrast, improper fillet cutting appears more closely associated with operator technique, knife condition, and cutting precision, reflecting human-related variability rather than mechanical limitations [24]. Labeling errors were most notable in November (4 cases) and remained present in December (2 cases), suggesting that manual labeling activities are also sensitive to workload increases. Although labeling defects do not directly compromise product safety, they affect traceability accuracy, regulatory compliance, and overall product presentation [25]. Residual scales were recorded intermittently across most months, with a slight increase in December (3 cases), indicating occasional inconsistencies during scaling and trimming processes.

Overall, the data demonstrate that defect occurrence is influenced by both human factors (operator skill, attention, workload, and training) and equipment-related factors (vacuum machine calibration, sealing temperature control, and maintenance). Defect patterns vary with production intensity, with processing defects more prominent during moderate production levels and packaging defects becoming dominant during peak output periods. This trend highlights the importance of strengthening both operator supervision and equipment monitoring, particularly during high-volume production seasons.

b. Pareto Diagram

The Pareto chart (Figure 3) summarizes the distribution of defects recorded during the observation period, totaling 68 cases. Improper fish cutting is the most frequent defect (42.65%), followed by vacuum leakage (35.29%), together representing nearly 78% of all defects. This pattern aligns with basic quality control principles, where a few "vital" causes drive most problems and should be the focus of corrective efforts, as documented in statistical quality control research using Pareto diagrams to prioritize defect sources in food production processes [26].

Improper cutting defects reflect inaccuracies in the processing stage that affect product uniformity and final quality. Quality challenges during manual processing are common in aquaculture and food processing operations, where operator skill, procedure consistency, and process conditions influence defect occurrence [27]. Studies using statistical analysis and Pareto methods in frozen seafood and related food processing show that defects often originate from human and procedural variability in semi-automatic manufacturing environments [26]. Vacuum leakage ranks second, with 24 cases or 35.29% of total defects. When combined with improper fish cutting, these two categories contribute 77.94% of all recorded defects, as reflected in the cumulative percentage line. The steep rise of the cumulative curve across the first two categories illustrates that the majority of quality problems are concentrated in these areas.

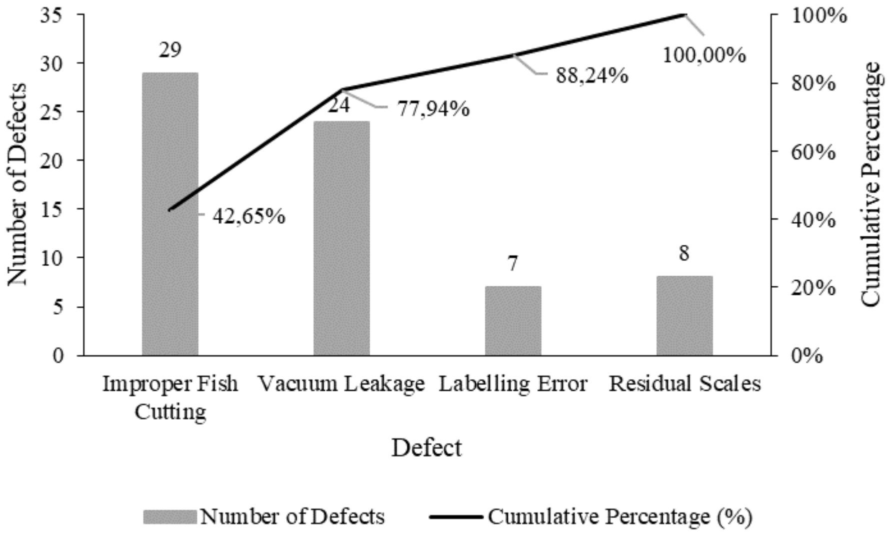

Figure 3. Pareto Diagram of Defective Products

This confirms that both processing (cutting) and packaging (vacuum sealing) stages are the most critical points requiring improvement. Labeling errors and residual scales contribute considerably fewer cases. Labeling errors account for 7 cases (10.29%), while residual scales represent 8 cases (11.76%). Together, these two defects make up the remaining 22.06% of total defects. In the Pareto chart, their bars are shorter, and the cumulative percentage curve begins to level off after the second category, indicating a smaller relative impact on overall defect frequency [28], [29].

Labeling errors and residual scales represent smaller portions of total defects, but still complete the defect profile in the Pareto chart. Quality control literature in food and packaging processes highlights that human factors and machine performance contribute to these lower-frequency defects, and that systematic monitoring and training can help reduce their occurrence [30]. While they contribute less to the overall defect count, addressing these categories still supports a comprehensive quality improvement strategy.

In conclusion, the Pareto analysis clearly demonstrates the 80/20 principle, where a small number of defect types account for the majority of problems. Since improper fish cutting and vacuum leakage together represent nearly 78% of total defects, prioritizing corrective actions in these two areas would yield the most significant improvement in product quality. Therefore, management efforts should focus on enhancing operator cutting skills, standardizing filleting procedures, and improving vacuum sealing machine performance and maintenance to achieve the greatest reduction in defect rates.

c. P-Control Chart (p-Chart)

The p-Control Chart (p-Chart) in Figure 4 monitors the monthly proportion of defective products from August 2025 to February 2026. The center line (CL) represents the average defect proportion (approximately 0.0025), while the upper control limit (UCL) and lower control limit (LCL) define the statistically expected range of variation under stable process conditions. Throughout the seven months, all observed defect proportions remain within the control limits, indicating that the process is statistically in control and that the observed variations are due to common causes rather than special causes. The p-chart is widely used in food manufacturing to monitor the fraction defective when sample sizes vary, and it is recommended for attribute data in quality control systems [31].

A gradual increase in the defect proportion is observed from August to December, with December showing the highest value (around 0.0034), followed by a noticeable decline in January and February. Although December approaches the upper control limit, it does not exceed it, meaning the increase is statistically acceptable but operationally significant. According to recent quality management research, trends approaching control limits may indicate emerging process stress, such as increased workload or equipment strain, and should trigger preventive investigation even when the process remains in control [31], [32]. This aligns with peak production periods where higher output can increase defect opportunities without necessarily causing statistical instability.

The subsequent decrease in January and February suggests improved process stability or reduced production pressure. The absence of out-of-control signals (no points beyond limits and no non-random patterns such as sustained runs above the center line) indicates that corrective measures or reduced production intensity helped maintain consistent quality performance. Contemporary food safety and quality standards emphasize continuous monitoring through statistical process control (SPC) tools like p-charts to ensure early detection of variation and support data-driven improvement decisions [33]. Hence, the chart confirms that the production system is statistically stable but highlights December as a month requiring closer operational review.

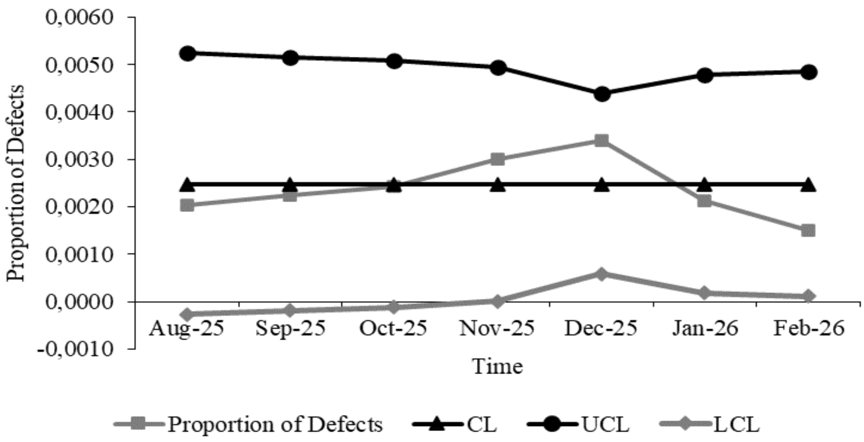

Figure 4. P-Control chart (p-Chart)

Fishbone Diagram

The fishbone (Ishikawa) diagrams in Figure 5 illustrate the root causes of four major defects, namely improper fillet cutting, vacuum leakage, labelling error, and residual scales, grouped into four key categories, namely methods, machines, materials, and manpower. This structured cause–and–effect analysis aligns with contemporary quality management practices that emphasize systematic identification of process variability sources in food manufacturing. According to recent quality engineering literature, fishbone diagrams are effective tools within Statistical Process Control (SPC) to diagnose recurring defects and guide corrective action planning [34]. By categorizing causes into controllable operational domains, the diagrams support targeted interventions rather than generalized corrective measures.

For improper fillet cutting and residual scales, the dominant causes are strongly linked to manpower and methods, such as insufficient training, lack of standardized procedures, operator fatigue, and high processing speed. Variability in raw material characteristics, such as fish size, texture, and thawing condition, also contributes to inconsistency in cutting accuracy and scaling effectiveness [24]. Recent studies in seafood processing highlight that human skill variability and raw material heterogeneity significantly influence defect rates in manual or semi-automated filleting operations [35]. These findings support the need for standardized operating procedures (SOPs), structured training programs, and raw material quality control to reduce physical defects in fish processing lines.

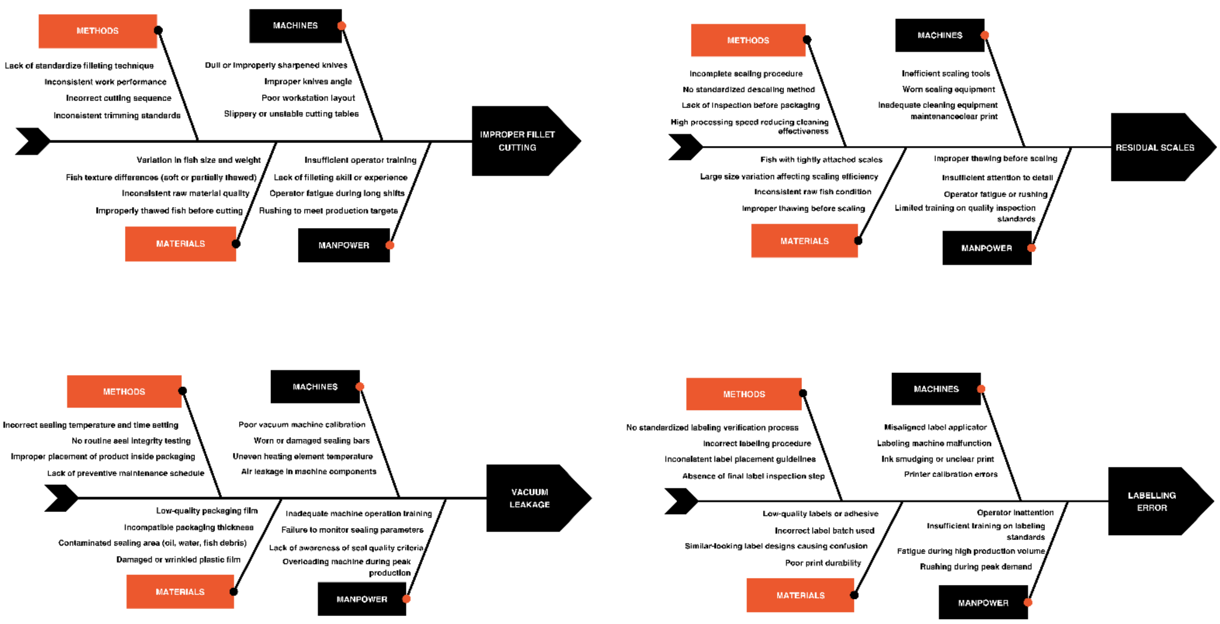

Figure 5. Fishbone Diagram

In contrast, vacuum leakage and labelling errors are more closely associated with machine performance and method control. Issues such as incorrect sealing temperature, worn sealing bars, poor calibration, misaligned label applicators, and inadequate verification procedures reflect weaknesses in equipment maintenance and operational monitoring. Modern food packaging research emphasizes that seal integrity management, preventive maintenance, and automated verification systems are critical to minimizing packaging-related defects [36]. Therefore, the fishbone analysis demonstrates that defect occurrence results from an interaction between human factors, equipment reliability, procedural control, and material quality, reinforcing the importance of integrated quality management systems in food processing industries.

B. Failure Mode and Effect Analysis (FMEA)

The Failure Mode and Effect Analysis (FMEA) results indicate that improper fillet cutting has the highest Risk Priority Number (RPN) of 168, followed by residual scales with an RPN of 90, and vacuum leakage with an RPN of 72, as shown in Table 3. The high RPN for improper fillet cutting is mainly attributed to its relatively high severity score (S = 7) and high occurrence score (O = 8), indicating that this defect has a substantial impact on product quality, yield reduction, and customer complaints, while also occurring frequently in the production process. According to FMEA principles, failure modes with higher RPN values should be prioritized for corrective action because they represent greater overall risk to process performance and product quality.

The dominant causes of improper fillet cutting include a lack of standardized filleting techniques, dull knives, and insufficient operator training. These factors suggest that the primary risk source is related to human and procedural variability in the filleting operation. Similarly, residual scales (RPN = 90) are associated with incomplete scaling, rushing during processing, and inadequate inspection before packaging. Both failure modes highlight the importance of strengthening standard operating procedures (SOPs), operator training programs, and routine equipment maintenance to reduce defect occurrence [35]. Such findings are consistent with previous studies in food and seafood processing, which emphasize that process standardization and operator competency are essential for improving product consistency and minimizing defects [24], [35].

In contrast, vacuum leakage, although having a lower RPN than improper fillet cutting, remains a critical defect because it directly affects product shelf life, spoilage risk, and export acceptance. Its causes are linked to incorrect sealing temperature or time settings, worn sealing bars, and poor machine calibration, indicating that this risk is primarily associated with equipment performance and maintenance. The relatively lower detection score (D = 2) suggests that current controls, such as seal integrity checks and periodic machine maintenance, are fairly effective in identifying leakage defects. Meanwhile, labeling errors have the lowest RPN (6), reflecting low severity, occurrence, and high detectability through final visual inspection. Overall, the FMEA results demonstrate that improper fillet cutting should be the main priority for corrective action, followed by residual scales and vacuum leakage, to enhance quality control and reduce the risk of product rejection in export-grade barramundi fillet production.

TABLE 3.
FAILURE MODE AND EFFECT ANALYSIS

Potential Failure Mode	Effect of Failure	S	Potential Cause of Failure	O	Current Control	D	RPN
Improper fillet cutting	Reduced product quality, lower yield, and customer complaints	7	Lack of standardized filleting technique, dull knives, and insufficient training	8	Visual inspection after cutting; operator supervision	3	168
Vacuum leakage	Reduced shelf life, spoilage risk, and possible product rejection	6	Incorrect sealing temperature/ time; worn sealing bars; poor calibration	6	Seal integrity check; periodic machine maintenance	2	72
Labeling error	Traceability issues, regulatory non-compliance, customer dissatisfaction	2	Manual labeling mistakes, misaligned applicator, and a lack of verification	3	Final visual label inspection	1	6
Residual scales	Poor product appearance, customer complaints	6	Incomplete scaling; rushing; inadequate inspection before packing	3	Manual inspection before packaging	5	90

For manual labeling, a two-person verification process or the introduction of barcode scanning systems will significantly reduce traceability risks. Furthermore, to address human fatigue, often a root cause of "rushing" and scaling errors, production targets must be adjusted during peak seasons to include job rotation and mandatory rest breaks. These administrative controls, combined with revised scaling SOPs that introduce a specific checkpoint before packaging, create a multi-layered defense against quality defects [27].

TABLE 4.
RECOMMENDATIONS FOR CORRECTIVE ACTION

No	Potential Cause of Failure	Current Control	Recommended Corrective Action	Responsible	Timeline
1	Lack of standardized filleting technique	Visual inspection after cutting; operator supervision	Develop and implement standardized filleting SOP; conduct periodic skill certification and hands-on training	Production Supervisor / QA Manager	1-2 months
2	Dull or improperly sharpened knives	Manual knife checking before shift	Establish a scheduled knife sharpening program; maintain a sharpening log sheet	Production Supervisor	Immediate (within 2 weeks)
3	Insufficient operator training (cutting and scaling)	On-the-job training	Conduct structured technical training and refresher programs; introduce a performance evaluation system	HR Department / QA Manager	1 month
4	Incorrect sealing temperature and time setting	Seal integrity spot check	Standardize sealing parameter settings; implement digital monitoring and a daily parameter verification checklist	Maintenance Team / QA	1 month
5	Worn or damaged sealing bars	Periodic machine maintenance	Increase preventive maintenance frequency; maintain spare part inventory for critical components	Maintenance Manager	Immediate and ongoing
6	Poor vacuum machine calibration	Monthly calibration	Implement weekly calibration verification and documented calibration records	Maintenance Team	1 month
7	Manual labeling errors/lack of verification	Final visual label inspection	Introduce double-check system (two-person verification); use barcode or automated label verification system	QA Team / Production	1-2 months
8	Misaligned label applicator/printer calibration errors	Machine check before operation	Schedule regular labeling machine alignment check and printer calibration	Maintenance Team	2-4 weeks
9	Incomplete scaling procedure	Manual inspection before packaging	Revise scaling SOP; introduce inspection checkpoint before vacuum packaging	Production Supervisor / QA	1 month
10	High processing speed causes operator fatigue	Supervisor monitoring	Adjust production targets during peak season; implement job rotation and rest breaks	Production Manager	Immediate (within 2 weeks)

IV. CONCLUSION

This study demonstrates that integrating Statistical Process Control (SPC) and Failure Mode and Effect Analysis (FMEA) provides an effective framework for improving quality control in export-grade barramundi (Lates calcarifer) fillet processing. Although SPC results indicated that the production process remained statistically stable, Pareto analysis revealed that improper fillet cutting and vacuum leakage accounted for nearly 78% of total defects. FMEA further identified improper fillet cutting as the most critical failure mode due to its high severity and limited detectability, resulting in the highest Risk Priority Number (RPN). These findings highlight that statistical stability does not necessarily equate to low operational risk, emphasizing the need for risk-based prioritization. Therefore, strengthening operator standardization, preventive maintenance, sealing parameter control, and verification systems is essential to reduce defects, enhance export compliance, and ensure consistent product quality in seafood processing operations.

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