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Technology readiness evaluation in dry choux pastry SMEs

Amenda Septiala Tarigan

Industrial Engineering Department, Faculty of Engineering, Universitas Pembangunan Nasional Veteran Jakarta, Indonesia

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ABSTRACT

This study evaluated the readiness level of technoware (equipment and machinery) and humanware (workforce competency) in a small-scale dry choux pastry enterprise to comply with the Indonesian National Standard (SNI) 2973:2011 for biscuits. The assessment was conducted using the Quality Function Deployment (QFD) framework and Analytical Hierarchy Process (AHP) to align customer needs and product quality standards with the production processes. Expert-based scoring was applied to measure the technological sophistication of production equipment and human capabilities based on UNESCAP classifications. The study identified the gap between actual conditions and the standard requirements by calculating aggregate scores for both technoware and humanware components across each production stage. The results revealed readiness gaps reaching 50.3% in microbial safety and 49.5% in free fatty acid (FFA) control, with technoware deficiencies most severe in packaging and filling, while humanware gaps were prominent in ingredient preparation and cooking. Improvement priorities were proposed using planning and technical matrices to calculate improvement ratios and normalized weights. Key improvement targets included moisture content control (improvement ratio = 1.28), flavor consistency, and heavy-metal safety. To assist micro and small bakery enterprises, this research suggests that incremental investments be made in PID-controlled ovens, stainless steel trays, and structured operator training in GMP and sensory evaluation. The main objective of this study is to develop a diagnostic framework that guides SME owners in prioritizing technology and competency upgrades to achieve sustainable compliance with SNI 2973:2011. The study concludes that a strategic focus on upgrading both machinery and human skillsets is essential for small food enterprises aiming to meet national food safety and quality standards.

Corresponding Author:

Amenda Septiala Tarigan,
Industrial Engineering Department,
Universitas Pembangunan Nasional Veteran Jakarta,
Jl. Limo Raya, Depok, West Java, 16515, Indonesia.
Email: amenda.tarigan@upnvj.ac.id

1. INTRODUCTION

Small and medium-sized enterprises (SMEs) dominate Indonesia's food sector and supply a substantial share of the nation's processed foods, yet limited resources, knowledge gaps, and weak enforcement make it difficult for them to keep pace with tightening food-safety rules, undermining both consumer protection and fair competition (Fajarwaty, 2022). Within the fastest-growing bakery segment—cookies, biscuits, and choux pastries—*dry choux pastry* (locally known as *sus kering*) has risen in popularity thanks to its crisp texture, long shelf-life, and flavour versatility (Rajan, 2025). To reach modern retail shelves or export markets, biscuit and pastry producers must meet Indonesia's mandatory standard SNI 2973:2011, which specifies physicochemical, microbiological, and heavy-metal limits equivalent to larger ASEAN benchmarks; nonetheless, certification remains rare, with only a fraction of registered brands deemed compliant (Hardjomidjojo, 2018). The integration of technology in Indonesian SMEs plays a strategic role in enhancing business performance, particularly within the manufacturing sector as the country undergoes structural economic transformation (Lee, 2022).

Unlike large manufacturers, small bakeries rely heavily on semi-manual equipment, informal operating procedures, and tacit worker know-how (Senjaya, 2024). Previous surveys of Indonesian SME bakeries show that only 38 % routinely calibrate ovens, 27 % record critical quality-control (QC) data, and fewer than 15 % train staff in systematic hygiene practices (Liestyana, 2021). Moreover, the low productivity among Indonesian food-sector SMEs has been closely linked to insufficient technological capabilities and a poor implementation of standardized operating procedures throughout production, further exacerbating compliance challenges (Sabardi, 2014).

These limitations often stem from two critical sources: outdated physical tools (technoware) and underqualified human resources (humanware), both of which are essential to ensuring operational efficiency and product compliance. As noted in recent empirical work, technoware functions as the core of production transformation, but its effectiveness is directly tied to how well humanware—skilled personnel with sufficient knowledge and training—can operate and manage it. Deficiencies in either area result in inefficient resource utilization and inconsistent quality outcomes (Anif, 2023). This observation is consistent with UNESCAP's framework (UNESCAP, 1989), which emphasizes that technoware and humanware must be developed in a balanced and complementary manner to build resource-constrained environments in technological capability.

Despite its importance for competitiveness in the industry 4.0 era, many small manufacturers in Indonesia still struggle with limited technological readiness due to gaps in infrastructure and technical expertise (Lee, 2022). Limited digital literacy remains a critical barrier that restricts MSMEs from fully utilizing technology, thereby undermining their ability to improve operational efficiency and meet regulatory quality standards (Oktavianti, 2025). Human resource competence plays a critical role in determining how effectively MSMEs can adopt and integrate technology into their production processes, particularly in enhancing product quality and operational control. Consequently, there is a pressing need for a structured diagnostic framework enabling SMEs to systematically pinpoint deficiencies in technological resources and workforce competencies, and to prioritize limited investment to improve digital maturity and operational readiness (Gonzalez-Varona, 2021).

The technometrics model from UNESCAP partitions organisational technology into four components—technoware (hardware), humanware (people competencies), infoware (documented knowledge), and orgaware (management systems) (Siregar, 2016). Empirical findings show that in micro-scale food industry clusters, production performance is primarily driven by technoware (such as operational equipment) and humanware (like entrepreneurial motivation). In contrast, infoware (e.g., production documentation) and orgaware (e.g., environmental and marketing management) tend to have a secondary influence, becoming more relevant as businesses mature or scale up (Taib, 2014). A case study in an electrical-machinery firm further demonstrates that systematic assessment of humanware—using criteria such as creativity, teamwork orientation, and risk-taking—helps align workforce capabilities with new technology and identifies integrity as a decisive bottleneck that can be addressed through targeted mentoring (Wiratmadja, 2014). Complementing these findings, addressing mismatches between operator skills and aging machinery through scheduling optimisation and focused training cut mean production time by 50 % and slashed waiting time by 95 % (Akbar, 2016). Yet the lack of awareness among SME owners regarding effective technology adoption continues to contribute to underutilization and hinders performance gains that digitalization could offer (Lee, 2022).

In line with prior studies, achieving compliance with food standards depends not only on formal protocols but also on the readiness of equipment and workforce competencies. Gaps in operator skills—such as inconsistent handling procedures and poor production scheduling—along with outdated or semi-manual machinery, often result in product non-conformance. Addressing these issues through structured diagnostic assessments and targeted improvements, such as equipment calibration and skill-based training, can substantially enhance production efficiency and compliance outcomes. These findings support the central argument that technoware and humanware are the most critical dimensions for improvement in resource-constrained production settings like Indonesian SME bakeries (Akbar, 2016). Technometric assessment provides a clear roadmap for modernization: the highest sophistication was found in orgaware and infoware, yet the greatest improvement priority remained technoware and humanware, which directly affect day-to-day compliance with food-safety requirements (Aji, 2023). At the same time, policy intervention is needed to close the knowledge-technology divide, especially by promoting infrastructure development and capacity building among SME food processors (Lee, 2022).

Despite extensive documentation on SME challenges and technology gaps, there remains no practical framework that explicitly diagnoses readiness levels in both machinery and human capability specific to SNI 2973:2011 compliance for dry choux pastry producers. This lack of clarity prevents small enterprises from identifying critical bottlenecks and formulating cost-effective interventions. Building on these insights, recent researches prioritize technoware and humanware, as these two dimensions often represent the most immediate causes of performance gaps in small-scale production environments, particularly where financial limitations prevent simultaneous development across all technometric components (Putri, 2017), (Nurrizki, 2024), (Lagunes, 2017), (Yaakob, 2014). Therefore, this study aims to develop a structured diagnostic model to evaluate and prioritize technoware and humanware improvements in dry choux pastry SMEs, ensuring that compliance with SNI 2973:2011 becomes both attainable and sustainable. A recurring issue in SME transformation is the misalignment between technological assets and human resource competencies, underscoring the need for synchronized development (Lee, 2022).

2. RESEARCH METHOD

This study integrated the UNESCAP technometrics framework with a hybrid Quality Function Deployment–Analytical Hierarchy Process (QFD–AHP) approach to evaluate the technological readiness of a micro-scale dry choux pastry enterprise located in Bandung, West Java, Indonesia. The investigation followed a sequential explanatory case-study design in which qualitative field observations were first collected and then embedded in a quantitative multi-criteria model. The work began with document analysis, during which the requirements of SNI 2973:2011 were translated into eight customer-need categories:

colour, flavour, texture, moisture content, protein level, free-fatty-acid threshold, heavy-metal contamination, and microbiological safety (Nasional, 2011). These attributes formed the “voice of the customer” within the House of Quality.

Following that, the entire production flow of the case enterprise was mapped through direct observation, time-lapse video, and semi-structured interviews, yielding a nine-stage process sequence that runs from ingredient preparation to final packaging. Each stage was then assessed by a panel consisting of a food technologist, an external quality-assurance consultant, and the business owner. Using a seven-point readiness scale adapted from NASA’s Technology Readiness Levels and UNESCAP’s technometrics classification, the experts rated both technoware (machinery and equipment) and humanware (operator competence) for every stage.

Although the full UNESCAP technometric model includes four components (technoware, humanware, infoware, and orgaware), this study focuses on technoware and humanware due to their direct and immediate impact on production compliance in micro-scale bakeries. Prior empirical studies have shown that infoware and orgaware tend to exert greater influence in larger or more mature enterprises (Taib, 2014) (Aji, 2023), whereas technoware and humanware are primary drivers in small, informal production settings.

The resulting scores provided the foundation for the QFD matrices that link customer needs to technical processes. To establish the relative importance of those links, the same experts completed pairwise-comparison questionnaires. Eigenvector calculations—performed in accordance with the AHP method—produced two weight vectors: W_k for process stages and WS_j for product-quality attributes. Only comparison matrices with consistency ratios below 0.10 were accepted (Hsiao, 2025), ensuring logical coherence.

The QFD–AHP method has been previously validated in SME contexts for process optimization and investment prioritization (Baritto, 2020); however, its integration within a technometric readiness framework in the Indonesian food sector represents a novel contribution of this study. To ensure the objectivity and validity of the readiness scores, the assessment process did not rely solely on the business owner's input. Instead, all ratings were triangulated with structured field observations and cross-validated by independent experts specializing in food safety and production systems. Any discrepancies in scoring were resolved through consensus-based discussions among the assessment panel. Notably, the selected enterprise has expressed a formal intention to pursue SNI 2973:2011 certification within the next two years, which positions this readiness evaluation as both a diagnostic exercise and a preparatory step toward compliance.

With relationship strengths, stage weights, and attribute weights in place, the model calculated aggregated these into composite readiness scores comparing the standard (ATS and AKS) and for actual factory practice (ATI and AKI). From these, improvement ratios (IR), interest points (IP), and raw weights (RW) were derived, enabling the ranking of upgrade priorities.

To quantify readiness levels, the study applied a multi-criteria evaluation model combining AHP and QFD, as adapted from previous technometric assessments. The readiness score for each component (technoware and humanware) was calculated as:

$$Readiness\ Score = \frac{\sum_{i=1}^{n} Subcomponent\ Scores}{n} \quad (1)$$

Using AHP, pairwise comparisons were conducted to determine priority weights *(w)*, where:

$$A \cdot w = \lambda_{max} \cdot w \quad (2)$$

For QFD analysis, the relationship between technical processes and product attributes was modeled as:

$$W_k = \sum_{j=1}^{m} R_{kj} \cdot W_{Sj} \quad (3)$$

Finally, to identify the gap between standard and actual practices, aggregated readiness indices were calculated:

$$AKS = \sum_{i=1}^{n} (R_i \cdot T_i) \quad (4)$$

$$AKI = \sum_{i=1}^{n} (R_i \cdot T'_i) \quad (5)$$

and improvement priorities were ranked using:

$$IP_i = \frac{AKS_i - AKI_i}{AKS_i} \cdot W_i \quad (6)$$

This methodological approach emphasizes structured assessment tools to help SMEs pinpoint technology readiness and prioritize digital transformation efforts effectively (Baritto, 2020). To promote reproducibility, entire procedure is summarised in Figure 1. Beyond internal reliability testing using Cronbach's alpha (which exceeded 0.80), robustness of the model was further evaluated using one-at-a-time ±10% sensitivity analysis on AHP weights. Additionally, consistency ratios were maintained below 0.10 for all matrices to confirm logical soundness and scoring stability.

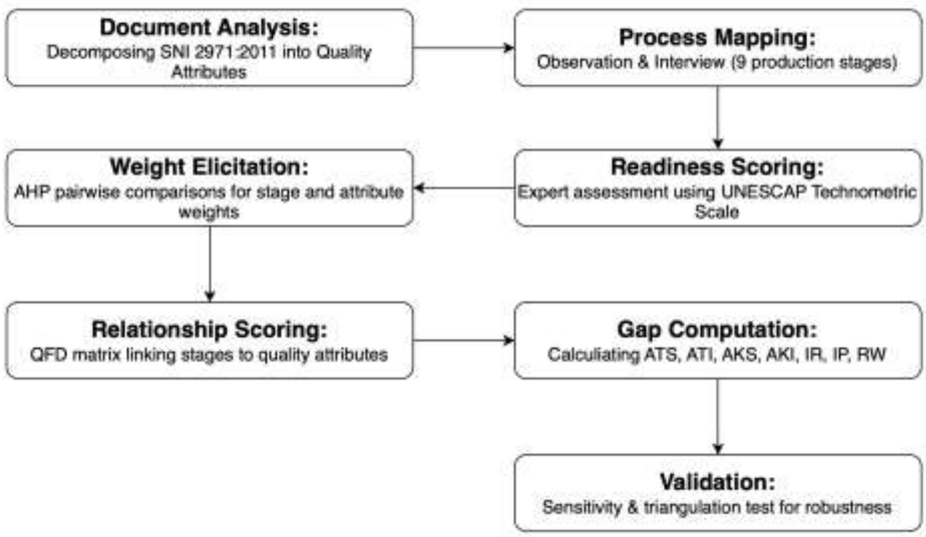

Figure 1. Chronological Workflow of Research

Model robustness was checked through a ±10 % one-at-a-time sensitivity analysis on all AHP weights. Rank-order correlations above 0.85 confirmed that priority listings were stable. Triangulation of observation notes, interview transcripts, and production-log data further strengthened construct validity. All instruments—observation checklists, technometric rating forms, AHP templates, and QFD worksheets—were pre-tested; Cronbach's alpha values exceeded 0.80, indicating satisfactory reliability. Ethical approval was obtained from the Industrial Engineering Ethics Committee of the authors' institution, and all respondents provided informed consent.

3. RESULTS AND DISCUSSIONS

The readiness evaluation in this study was conducted across nine critical stages of dry choux pastry production, beginning with raw material preparation and ending with final packaging. These stages—illustrated in Figure 2—represent the complete production lifecycle observed at the small and medium enterprise (SME) and were assessed against the quality parameters outlined in the Indonesian National Standard (SNI) 2973:2011 for biscuits. Each process stage was evaluated for its contribution to product quality through two key dimensions of readiness: technoware, referring to the availability and adequacy of tools and machinery, and humanware, referring to the competencies and skills of workers involved. The ideal characteristics of dry choux pastry include uniform expansion, light texture, hollow centers, and golden-brown crusts—attributes that stem from precise choux paste handling and serve as benchmarks for product quality (Handajani, 2019). In line with this, consumer-accepted choux pastry products are also expected to display neat, rounded forms with a crisp outer layer and soft interior, regardless of ingredient formulations (Syukra, 2024). Achieving these standards depends not only on the functional precision of the production equipment—such as mixers, ovens, and dispensers—but also on the workers' ability to execute consistent processes involving temperature control, batter preparation, and timing. By aligning regulatory benchmarks with field conditions through a hybrid framework combining Quality Function Deployment (QFD) and the Analytical Hierarchy Process (AHP), this study presents a structured diagnosis of the SME's capacity to achieve compliance with national food quality standards.

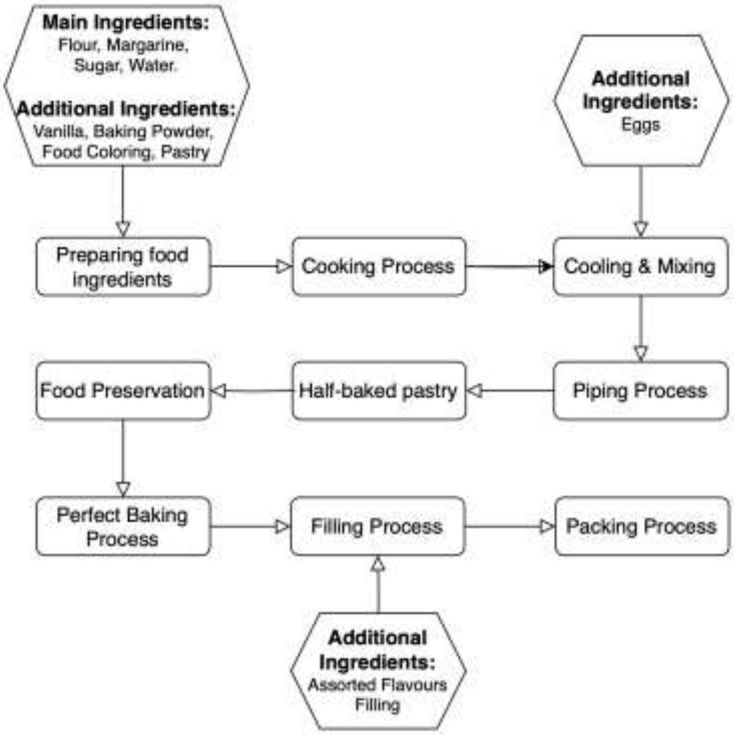

Figure 2. Dry Choux Pastry Production Flow

The analysis revealed significant discrepancies between current readiness levels and SNI targets. Technoware deficiencies were especially prominent in downstream operations such as filling and packaging, where limited hygienic controls and absence of semi-automated systems contributed to substantial quality risks. Conversely, humanware gaps were most evident in early-stage processing—namely ingredient preparation and cooking—where tasks remain largely manual and under-standardized.

Figure 3. Dry Choux Pastry Production Flow

Figure 3 illustrates the comparative readiness gaps between actual and target values for both humanware and technoware components across key product-quality parameters. The left panel shows that humanware gaps are most pronounced in sensory attributes such as normal colour and odour, as well as in microbial control—highlighting the need for improved training and standardized operating procedures. Conversely, the right panel reveals that technoware deficiencies are concentrated in hygiene-sensitive indicators such as microbial safety and free fatty acid levels, pointing to outdated or insufficient equipment. Together, the radar charts emphasize the most critical gaps of humanware and technoware, especially in microbial safety and FFA control. These patterns are detailed in Table 1, which compares the SME's actual technoware (ATI) and humanware (AKI) scores with the expected thresholds (ATS and AKS) across eight key product-quality parameters.

Table 1**.** Overall Readiness versus SNI Targets

SNI Quality Parameter	ATS (Target)	ATI (Actual)	Tech-Gap (%)	AKS (Target)	AKI (Actual)	Human Gap (%)
Normal colour	2.609	2.208	15.4	2.051	1.475	28.1
Normal odour	2.609	2.208	15.4	2.051	1.475	28.1
Normal flavour	2.971	2.366	20.4	2.164	1.724	20.3
Moisture ≤ 5 %	3.082	2.403	22.0	2.201	1.761	20.0
Protein ≥ 5 %	1.055	0.654	38.0	1.053	1.053	0.0
Free fatty acid ≤ 1 %	1.006	0.508	49.5	0.800	0.936	-17.0
Heavy-metal limits	2.550	2.091	18.0	1.642	1.124	31.5
Microbial limits	0.881	0.438	50.3	0.574	0.694	-20.9

As presented in Table 1, the most critical technoware gaps were identified in free fatty acid (FFA) content (49.5%) and microbial safety (50.3%), reflecting severe limitations in hygiene-related equipment and process control. Other notable technoware deficiencies above 20% were recorded for moisture content, flavour, and heavy-metal limits, highlighting the inadequacy of ovens, mixers, and material-contact surfaces. Regarding humanware, the largest gaps were recorded in heavy-metal monitoring (31.5%), sensory evaluation of colour and odour (28.1%), and flavour/moisture handling (~20%), all of which point to the need for systematic training in sensory quality control and Good Manufacturing Practices (GMP). Notably, no humanware gap was observed for protein content, suggesting that workers possess the necessary competencies in basic formulation tasks. Additionally, negative humanware gaps in FFA (−17.0%) and microbial safety (−20.9%) imply that operator knowledge and hygiene awareness slightly exceed the capabilities of the current equipment. This misalignment suggests that the SME's human resources are underutilized due to technological constraints. Therefore, selective upgrades to technoware infrastructure—particularly in hygiene-sensitive stages—along with the alignment of capital spending to existing workforce capacity, will be key to achieving SNI 2973:2011 compliance.

The QFD–AHP weighting analysis, as summarized in Table 2, identified the Final Baking (28.8%) and Cooking (14.7%) stages as having the highest relative influence on final product quality in dry choux pastry production. These two stages accounted for over 43% of the total process weight, underscoring their centrality in achieving compliance with SNI 2973:2011 quality targets. This finding aligns with product characteristics such as moisture content, texture, and microbiological stability, which are highly sensitive to time–temperature precision and hygienic handling during these thermal processing stages.

Table 2. QFD–AHP Weighting Results

Production Stage	Weight (%)
Preparing Ingredients	7.0
Cooking	14.7
Cooling & Mixing	8.4
Piping	6.5
Half-baked pastry	7.5
Filling	10.8
Perfect Baking	28.8
Packing	11.6
Preservation	4.6

Further analysis of technoware and humanware readiness revealed distinct bottlenecks at specific points in the production line. Technoware gaps were most prominent in the filling and packaging stages. In the filling stage, the continued use of manual piping tools without standardized portion control contributes to variability in fat content and exposure to air, leading to elevated free fatty acid levels and an increased risk of rancidity. In the packaging stage, the absence of advanced equipment—such as nitrogen flushing or vacuum-sealing systems—results in residual oxygen that compromises microbial safety and shelf-life. These downstream stages are particularly critical as they directly affect the product's long-term stability and regulatory compliance.

On the other hand, humanware gaps were most pronounced in the ingredient preparation, cooking, and cooling-mixing stages. These early-stage activities rely heavily on manual labor, experiential knowledge, and uncalibrated tools. In the absence of clear standard operating procedures, workers tend to estimate ingredient proportions and heating times, which increases the risk of non-uniformity in color, odor, and moisture content. Moreover, the use of non-food-grade utensils during these early stages may result in unintended contamination with heavy metals. While later stages show better humanware alignment—partly due to the repetitive and structured nature of tasks—the early processing steps remain a major area of concern. These findings underscore the need for targeted investment and skill development, tailored to the specific technological and procedural weaknesses of each production phase. Rather than applying uniform upgrades across all stages, strategic improvements focused on critical nodes in the process will yield the most effective path toward achieving SNI 2973:2011 compliance.

These results are consistent with earlier research by (Akbar, 2016), which demonstrated that targeted alignment between human competence and process-critical equipment significantly reduces production inefficiencies in small manufacturing contexts. Similar to the findings by (Taib, 2014) and (Aji, 2023), this study reaffirms that technoware and humanware remain the most influential factors in micro-scale operations. However, this study extends prior work by applying QFD–AHP integration to link readiness directly to national compliance benchmarks (SNI 2973:2011), an approach not yet employed in previous bakery-sector studies.

Moreover, the observed "negative humanware gaps," where operator skills exceeded equipment capability, diverge from past assumptions in the literature—such as those by (Fajarwaty, 2022) and (Hardjomidjojo, 2018)—which generally positioned undercapitalization as the dominant barrier. This study offers a refined interpretation by quantifying readiness asymmetry, highlighting the strategic advantage of phased upgrades rather than total system overhauls.

Ultimately, this study contributes not only actionable insights but also a theoretical refinement in understanding how readiness can be optimized when tools and people are aligned toward common quality objectives.

4. CONCLUSION

This study addressed the challenge of SNI 2973:2011 compliance in Indonesian SME bakeries by evaluating technoware and humanware readiness using an integrated QFD–AHP technometric framework. The results identified microbial safety and free fatty acid control as the most critical gaps—both exceeding 49%—and highlighted Final Baking and Cooking as the stages with the highest quality impact. These findings underscore the dual role of equipment and workforce capability in determining food safety outcomes and support a strategy of incremental upgrading aligned with operator skills. The proposed diagnostic model not only contributes to theoretical advancement by integrating QFD–AHP within a technometric structure but also introduces the novel concept of readiness asymmetry, where human capacity may exceed technological resources. Practically, the model offers a structured, low-cost tool for SMEs and policymakers to prioritize targeted investments in quality compliance. Nonetheless, this study is limited by its focus on only two technometric components—technoware and humanware—without incorporating infoware or orgaware, and relies on self-assessment moderated by expert triangulation, which may introduce subjectivity. Future research should extend this model to include digital infoware systems, real-time monitoring through IoT integration, and comparative analysis across diverse food processing sectors to enhance generalizability and implementation scalability.

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