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Supply Chain Resilience and Competitive Advantage in Fish-Processing Firms: Digital Technology as a Mediating Capability from an Environmental Health Perspective

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Abstract. Fish-processing firms face continuous pressure to maintain product quality, supply stability, environmental responsibility, and market competitiveness. Their operations are closely linked to raw material uncertainty, cold-chain reliability, wastewater, fish residues, energy use, food-safety control, and traceability. This study examines how Supply Chain Resilience contributes to Competitive Advantage and how Digital Technology mediates this relationship. The research was conducted among fish-processing companies in Bitung City using a quantitative explanatory approach. The data were analyzed with Partial Least Squares Structural Equation Modeling through SmartPLS 4.0. The results show that Supply Chain Resilience has a significant effect on Competitive Advantage, with a t-statistic of 2.370 and a p-value of 0.018. Supply Chain Resilience also significantly affects Digital Technology, with a t-statistic of 6.721 and a p-value of 0.000. Digital Technology significantly contributes to Competitive Advantage, with a t-statistic of 3.070 and a p-value of 0.002. The indirect path also confirms the mediating role of Digital Technology, with a t-statistic of 2.289 and a p-value of 0.022. These findings indicate that resilience becomes more effective when supported by digital tools that strengthen visibility, monitoring, coordination, traceability, and data-based decisions. From an environmental health perspective, the integration of resilience and digital technology helps fish-processing firms manage operational disruption while improving product safety, environmental control, and sustainable competitiveness.

Keywords: competitive advantage; digital technology; environmental health; fish-processing firms; supply chain resilience

INTRODUCTION

Fish-processing firms work within supply chains that are sensitive to time, quality, and disruption. Raw fish must be obtained, processed, stored, and distributed under conditions that preserve freshness and safety. Any disturbance in raw material supply, transportation, cold storage, export procedures, or quality control can directly affect production continuity and market performance. For this reason, competitiveness in fish-processing firms is not determined only by price or production volume. It also depends on the ability of companies to maintain stable and responsive supply-chain systems.

The sector also has a strong environmental-health dimension. Fish-processing activities may produce wastewater, organic residues, solid by-products, odors, and high energy demand. These issues can affect environmental quality when not properly managed. Wastewater from seafood processing may contain organic loads, nutrients, salts, suspended solids, nitrogen, and phosphorus that require treatment before disposal (Al-Dawery et al., 2023; Katsara et al., 2025). Therefore, supply-chain continuity in this sector is connected not only to business performance, but also to environmental control and public health protection.

Fish waste and processing by-products also require serious attention. When discarded without proper management, these materials can become environmental burdens. However, when handled through circular-economy approaches, fish residues can be converted into useful products and reduce disposal pressure. Studies on fish-waste management and fish-waste biorefinery show that by-products can support sustainability when firms are able to organize waste streams more efficiently (Gill et al., 2025; Sultan et al., 2023). This indicates that environmental responsibility can become part of supply-chain strategy.

Traceability is another important issue in fish-processing supply chains. Seafood markets increasingly require clear information about product origin, processing, legality, handling, and distribution. Weaknesses in processing and distribution nodes can reduce the reliability of product information and weaken buyer confidence(Hopkins et al., 2024). Traceability is therefore not only a technical requirement. It is also a source of competitive value, especially for companies serving markets that demand quality assurance and sustainability evidence.

Cold-chain performance further strengthens the connection between supply-chain management and environmental health. Fish products require temperature-controlled systems to prevent quality deterioration and food-safety risks. At the same time, cold-chain systems consume energy and may contribute to environmental impacts. Research on food and aquaculture cold chains emphasizes that firms need to maintain product safety while improving energy efficiency and reducing environmental burden (Hsu & Lo, 2026; Marchi & Zanoni, 2022). Thus, fish-processing firms must balance operational reliability, safety, and environmental responsibility.

Within this context, Supply Chain Resilience becomes a critical organizational capability. Resilience refers to the ability of a supply chain to anticipate disruption, respond to change, adapt operations, and recover after disturbances. In fish-processing firms, resilience is needed when companies face unstable fish supply, weather-related delays, transportation problems, cold-storage failure, regulatory changes, or market uncertainty. Previous studies have shown that resilient supply chains can support sustainable competitive advantage through responsiveness, adaptability, and better supply-chain design (Pu et al., 2023; Sun et al., 2022).

However, resilience requires information. Firms cannot respond effectively to disruption when information is late, fragmented, or inaccurate. Digital Technology can strengthen resilience by providing visibility across supply-chain activities. Tools such as automation, Internet of Things, big data analytics, artificial intelligence, and blockchain can support monitoring, tracking, coordination, forecasting, and decision-making. Prior studies indicate that supply-chain digitalization improves resilience, performance, and competitive capability under uncertainty (Ning & Yao, 2023; Zhao et al., 2023).

Digital Technology is also relevant to environmental-health governance. Digital monitoring can help firms track cold-chain temperature, observe product movement, monitor resource use, identify process deviations, and support traceability. Blockchain and other traceability systems can increase transparency and trust in seafood supply chains (Mawrides et al., 2025; Thompson & Rust, 2025). Big data analytics may also help firms process information during disruption and develop more sustainable competitive advantages (Behl et al., 2022; Winkelmann et al., 2024).

Bitung City provides an appropriate setting for this study because it is one of the important fish-processing and seafood-export centers in North Sulawesi. Fish-processing firms in this area contribute to regional economic activity, but they also face challenges related to raw material availability, export requirements, cold-chain dependence, waste handling, wastewater management, energy use, and traceability. These conditions make resilience and digital capability highly relevant for maintaining competitiveness.

Previous studies have discussed supply-chain resilience, digital transformation, traceability, waste management, sustainability, and competitive advantage. Nevertheless, several issues still require further examination. First, resilience is often discussed mainly as a business-continuity capability, while its environmental-health relevance in fish-processing firms receives less attention. Second, digital technology is frequently positioned as an efficiency instrument, although it can also function as a system for monitoring, traceability, and environmental control. Third, empirical studies that examine Digital Technology as a mediator between Supply Chain Resilience and Competitive Advantage in Indonesian fish-processing firms remain limited.

This study addresses these gaps by examining Supply Chain Resilience, Digital Technology, and Competitive Advantage within an environmental-health-oriented supply-chain framework. The study argues that resilience enables fish-processing firms to maintain operations under disruption, while digital technology helps transform that resilience into competitive performance. Accordingly, this research analyzes the direct effect of Supply Chain Resilience on Competitive Advantage, the effect of Supply Chain Resilience on Digital Technology, the effect of Digital Technology on Competitive Advantage, and the mediating role of Digital Technology in fish-processing companies in Bitung City.

MATERIALS AND METHODS

This research examined the relationships among Supply Chain Resilience, Digital Technology, and Competitive Advantage in fish-processing companies in Bitung City, North Sulawesi, Indonesia. The study followed a quantitative explanatory approach because the main objective was to test the direction and significance of relationships among latent constructs in the proposed model.

Bitung City was selected as the research location because the area has an important role in fish processing and seafood export activities. Companies in this sector operate under conditions that require supply continuity, cold-chain reliability, product safety, processing efficiency, environmental compliance, and distribution stability. These characteristics make the sector suitable for studying how resilience and digital systems contribute to competitive advantage.

The model consisted of three constructs. Supply Chain Resilience was treated as the predictor variable. Digital Technology was placed as the mediating variable. Competitive Advantage was positioned as the outcome variable. Supply Chain Resilience reflects the ability of firms to maintain and recover supply-chain operations when disturbances occur. Digital Technology refers to the use of digital systems for monitoring, automation, data processing, coordination, traceability, and decision support. Competitive Advantage refers to a firm’s ability to perform better than competitors through price, quality, delivery, innovation, and time-to-market. The operational definitions of the variables are presented in Table 1..

Table 1. Operational Definitions of Research Variables

Variable	Operational Definition	Indicators
Supply Chain Resilience / SCRes (X)	The capability of a fish-processing company to maintain, adapt, and recover its supply chain operations when facing disruptions, while supporting environmental-health-related operational continuity.	Re-engineering, agility, collaboration, and supply chain risk management culture.
Digital Technology (M)	The use of digital systems and tools to support supply chain visibility, operational efficiency, risk monitoring, data-based decision-making, and environmental-health control in fish-processing activities.	Automation, Internet of Things, big data analytics, artificial intelligence, and blockchain.
Competitive Advantage (Y)	The ability of a fish-processing company to achieve a stronger market position through superior operational performance, product quality, responsiveness, and innovation.	Price, quality, delivery, innovation, and time-to-market.

Data were obtained through a structured questionnaire. The items were prepared based on the indicators of each construct and were designed to capture respondents’ perceptions of resilience capability, digital-technology use, and competitive advantage in fish-processing operations. The responses were measured using a Likert-type scale.

The data were processed with Partial Least Squares Structural Equation Modeling using SmartPLS 4.0. This analytical technique was selected because the model involved latent variables and included a mediating path. The analysis was carried out by first checking the measurement quality of the constructs and then evaluating the structural relationships among variables.

The measurement model was reviewed through indicator loading, Average Variance Extracted, Cronbach's Alpha, Composite Reliability, Fornell-Larcker criterion, cross-loading, HTMT, and VIF. These procedures were used to ensure that the indicators represented their constructs properly, that each construct was reliable, and that the constructs were sufficiently distinct from one another.

The structural model was examined through R-square, Q-square, F-square, and bootstrapping. R-square was used to determine the explanatory contribution of the model. Q-square was used to evaluate predictive relevance. F-square was used to identify the contribution of each predictor. Bootstrapping was used to test direct and indirect relationships based on t-statistics and p-values. A path was considered significant when the p-value was below 0.05.

Through this procedure, the study evaluated not only whether Supply Chain Resilience directly improves Competitive Advantage, but also whether Digital Technology helps explain how resilience is converted into competitive outcomes. This approach is relevant to fish-processing firms because digital systems may support operational continuity, product safety, traceability, environmental monitoring, and faster response to disruption.

RESULTS AND DISCUSSION

Measurement Model Evaluation

Before testing the hypotheses, the quality of the measurement model was assessed. The evaluation covered the three constructs used in the model: Supply Chain Resilience, Digital Technology, and Competitive Advantage.

The results confirmed that the indicators met the criteria for convergent validity. All outer loading values were above 0.70, showing that the indicators had strong relationships with their respective constructs. The AVE values were also above 0.50, indicating that each construct explained a sufficient proportion of the variance of its indicators.

The reliability results also supported the use of the measurement model. Cronbach's Alpha values were above 0.60, while Composite Reliability values were above 0.70. These results indicate that the indicators within each construct were consistent and suitable for further analysis.

Discriminant validity was supported by the Fornell-Larcker criterion, cross-loading values, and HTMT results. The square root of AVE for each construct was higher than the correlations with other constructs. Each indicator also loaded more strongly on its own construct than on other constructs. The HTMT values were below 0.90 after model adjustment. These results show that Supply Chain Resilience, Digital Technology, and Competitive Advantage were empirically different constructs.

The multicollinearity assessment showed that all VIF values were below 5. This means that the model did not contain serious collinearity problems. Therefore, the measurement model was considered appropriate for structural model testing.

Structural Model Evaluation

The structural model showed strong explanatory power for Competitive Advantage. The R-square value for Competitive Advantage was 0.768, meaning that Supply Chain Resilience and Digital Technology explained 76.8% of the variance in Competitive Advantage. The remaining 23.2% was associated with factors outside the model.

The R-square value for Digital Technology was 0.415. This means that Supply Chain Resilience explained 41.5% of the variance in Digital Technology, while the remaining 58.5% was influenced by other factors. This result indicates that resilience is an important contributor to digital-technology adoption, although other organizational, financial, and managerial factors may also play a role.

The Q-square values were 0.592 and 0.353. Both values were above zero, indicating that the model had predictive relevance. The F-square results also showed that the relationships among the constructs had meaningful effect sizes. Overall, the model was suitable for explaining how resilience and digital technology contribute to competitive advantage in fish-processing companies.

Hypothesis Testing

Hypothesis testing was carried out using the bootstrapping procedure in SmartPLS. The hypotheses were evaluated based on t-statistics and p-values. The results are presented in Table 2.

Table 2. Hypothesis Testing Results

Relationship	T-Statistic	P-Value	Result
SCRes - Competitive Advantage	2.37	0.018	Supported
SCRes - Digital Technology	6.721	0	Supported
Digital Technology - Competitive Advantage	3.07	0.002	Supported
SCRes - Digital Technology - Competitive Advantage	2.289	0.022	Supported

The first hypothesis was supported because the path from Supply Chain Resilience to Competitive Advantage produced a t-statistic of 2.370 and a p-value of 0.018. This result indicates that fish-processing firms with stronger resilience tend to have better competitive positions.

The second hypothesis was also supported. The path from Supply Chain Resilience to Digital Technology produced a t-statistic of 6.721 and a p-value of 0.000. This result suggests that resilient firms are more likely to adopt digital systems to support supply-chain activities.

The third hypothesis was supported by a t-statistic of 3.070 and a p-value of 0.002. This confirms that Digital Technology contributes significantly to Competitive Advantage. Firms that use digital systems more effectively are better positioned to improve quality, delivery, innovation, responsiveness, and market performance.

The fourth hypothesis confirmed the mediating role of Digital Technology. The indirect path from Supply Chain Resilience to Competitive Advantage through Digital Technology produced a t-statistic of 2.289 and a p-value of 0.022. This means that Digital Technology helps explain how resilience capability is transformed into competitive outcomes.

DISCUSSION

Supply Chain Resilience and Competitive Advantage

The results indicate that Supply Chain Resilience strengthens Competitive Advantage. In fish-processing firms, resilience is important because the production process depends on raw materials that are perishable and often uncertain in availability. Disruption in supply, storage, logistics, or regulation can affect product quality and delivery performance. Firms that are able to respond quickly to these challenges are more likely to maintain market trust.

Resilience supports competitiveness through several mechanisms. Agile firms can adjust production and distribution when disruption occurs. Collaborative firms can coordinate with suppliers, logistics providers, and buyers to reduce delays. Firms with a risk-management culture can prepare alternative responses before problems become severe. These capabilities help firms protect product quality, maintain delivery reliability, and respond to customer requirements.

From an environmental-health perspective, resilience also helps firms maintain control over safety and environmental processes. Disruption in cold storage, raw material supply, or wastewater treatment may create quality and environmental risks. Resilient firms are better prepared to keep these processes under control. Therefore, resilience contributes not only to business continuity, but also to safer and more responsible fish-processing operations.

For fish-processing firms in Bitung City, this finding is important because the sector is connected to both regional economic activity and export-market expectations. Companies must compete while also maintaining product quality, traceability, and environmental responsibility. Supply Chain Resilience therefore becomes a strategic capability that supports competitiveness in a demanding market environment.

Supply Chain Resilience and Digital Technology

The study found that Supply Chain Resilience significantly influences Digital Technology. This suggests that firms seeking to become more resilient tend to rely on digital tools. Resilience requires timely information, accurate monitoring, and coordination across supply-chain actors. Digital systems provide these capabilities.

In fish-processing operations, digital technology can be used to monitor raw materials, production schedules, cold-chain conditions, inventory, logistics, and product traceability. These functions make it easier for companies to detect problems early and respond before disruptions create larger losses. Digital systems therefore become part of the resilience-building process.

This result also implies that digital transformation may be driven by operational pressure. Firms that experience uncertainty in supply and distribution are more likely to recognize the need for better information systems. By adopting digital tools, companies can move from reactive responses to more planned and evidence-based responses.

The environmental-health relevance is also strong. Digital systems can help firms monitor cold-chain performance, product safety, waste handling, energy use, and environmental compliance. In this way, the relationship between resilience and digital technology supports both operational stability and environmental-health control.

Digital Technology and Competitive Advantage

Digital Technology has a significant effect on Competitive Advantage. This result shows that digital capability can improve the market position of fish-processing firms. Digital tools help companies process information faster, reduce errors, improve coordination, and make decisions based on data.

In fish-processing supply chains, digital technology can support competitiveness by improving visibility and traceability. Firms can monitor product origin, processing stages, storage conditions, and distribution flows. This information is valuable because buyers increasingly demand transparency, quality assurance, and sustainability evidence.

Digital systems can also improve operational efficiency. Automation can reduce dependence on manual processes. Internet of Things devices can support real-time monitoring of temperature and equipment. Big data analytics can help firms identify patterns in demand, supply, and risk. Artificial intelligence can support prediction and decision-making. Blockchain can strengthen the credibility of traceability data.

From an environmental-health perspective, digital technology improves accountability. Firms with better data can manage product safety, cold-chain stability, waste-control processes, resource use, and compliance more effectively. These capabilities strengthen reputation and customer trust. Therefore, Digital Technology contributes to Competitive Advantage not only through efficiency, but also through product integrity and environmental responsibility.

The Mediating Role of Digital Technology

The mediation result confirms that Digital Technology connects Supply Chain Resilience with Competitive Advantage. This means that resilience improves competitiveness partly because resilient firms use digital systems to strengthen their operations. Resilience provides the capability to adapt and recover, while digital technology provides the information infrastructure needed to make that capability effective.

This finding is important because resilience without information support may not produce optimal results. A company may have flexible processes and strong collaboration, but if information is delayed or fragmented, responses may still be slow. Digital technology helps overcome this limitation by providing visibility, monitoring, automation, and data-based decision-making.

In fish-processing firms, digital technology can convert resilience into competitive value through several pathways. It can improve cold-chain monitoring, quality control, supplier coordination, inventory planning, production scheduling, and traceability. These improvements can reduce delays, protect product quality, increase reliability, and improve customer trust.

From the environmental-health viewpoint, the mediation effect shows that digital systems make resilience more transparent and measurable. Digital tools help firms detect risks, monitor waste-related processes, maintain product-safety control, and support compliance. Thus, Digital Technology acts as a mechanism that transforms supply-chain resilience into sustainable competitive advantage.

Implications

The findings provide practical implications for fish-processing firms in Bitung City. First, companies need to strengthen Supply Chain Resilience by improving agility, collaboration, process redesign, and risk-management culture. These capabilities are important for maintaining production continuity, logistics reliability, quality control, and environmental-health performance.

Second, Digital Technology should be treated as a strategic capability rather than only a supporting tool. Automation, Internet of Things, big data analytics, artificial intelligence, and blockchain can help firms improve visibility, monitoring, traceability, and coordination. These systems can also support safer products, better cold-chain control, more efficient resource use, and stronger waste-management practices.

Third, Competitive Advantage should be developed through the integration of resilience and digital technology. Fish-processing firms need to compete through price, quality, delivery, innovation, and time-to-market, but these advantages will be stronger when supported by reliable data, traceable products, and responsive supply-chain systems.

Fourth, environmental health should be embedded into supply-chain strategy. Firms should not view waste, wastewater, cold-chain stability, and traceability as separate compliance issues. These aspects can become part of competitiveness when managed through resilient and digitally supported operations.

Fifth, external support from local government, industry associations, and related institutions may help accelerate digital adoption. Training, infrastructure, standards, and incentives can support fish-processing firms in building digital capabilities that improve both competitiveness and environmental-health performance.

CONCLUSION

This study demonstrates that Supply Chain Resilience, Digital Technology, and Competitive Advantage are closely connected in fish-processing companies in Bitung City. Supply Chain Resilience has a significant effect on Competitive Advantage, as shown by a t-statistic of 2.370 and a p-value of 0.018. Supply Chain Resilience also significantly affects Digital Technology, with a t-statistic of 6.721 and a p-value of 0.000. Digital Technology significantly affects Competitive Advantage, with a t-statistic of 3.070 and a p-value of 0.002.

The study also confirms that Digital Technology mediates the relationship between Supply Chain Resilience and Competitive Advantage. The indirect effect is significant, with a t-statistic of 2.289 and a p-value of 0.022. This result indicates that resilience generates stronger competitive outcomes when firms use digital tools to improve visibility, monitoring, coordination, traceability, and data-based decision-making.

From an environmental-health perspective, competitiveness in fish-processing firms should not be viewed only through price, quality, delivery, innovation, and time-to-market. It is also related to the ability to maintain product safety, cold-chain stability, waste control, wastewater management, resource efficiency, and traceability. Therefore, fish-processing companies need to integrate supply-chain resilience and digital technology to develop operations that are adaptive, transparent, competitive, and environmentally responsible.

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