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Supply Chain Performance Analysis of Processing Tomato Production in Thailand: A Multi-Dimensional Assessment

Tanakorn Rachapila

tanakorn.agribus@gmail.com

Sakon Nakhon Rajabhat University

Kingkan Pongtong

Ubon Ratchathani University

Taweesak Laohawiroje

Doi Kham Food Products Co., Ltd

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Abstract

Background

Measuring supply chain performance in agri-food systems has important implications for food security, inclusive rural development, and firm competitiveness. The processing tomato industry in Thailand provides a suitable case for examining coordination challenges in contract farming arrangements involving smallholder farmers.

Methods

This study develops and applies a comprehensive measurement framework comprising 56 indicators grouped into nine performance dimensions based on transaction cost economics and the SCOR model v14.0. Data were collected from 120 contracted farmers in Upper Northeastern Thailand during the 2023–2024 production season. Descriptive statistics and stochastic frontier analysis were employed to assess supply chain performance and technical efficiency.

Results

The results reveal substantial coordination gaps, particularly in joint problem-solving (ISP8 = 1.77 ± 1.11) and joint decision-making (ISP7 = 2.08 ± 1.09), as well as underdeveloped risk management and traceability capabilities (traceability testing capability = 31.13%). The supply chain remains economically viable with an average return on investment of 34.27% and yields of approximately 49 tonnes/hectare, although below international benchmarks of 70–80 tonnes/hectare. Average technical efficiency is estimated at 69.10%, implying considerable scope for productivity gains without additional inputs.

Conclusions

The study contributes to the literature by integrating relational, operational, and economic dimensions into a single framework for agricultural supply chain performance assessment in a developing country context. Policy and managerial recommendations are proposed to enhance coordination, support smallholder upgrading, and improve the international competitiveness of Thailand's processing tomato industry.

JEL Classification: Q12, Q13, D23, L14

Introduction

Measuring supply chain performance has become a central concern in agricultural economics and agribusiness management due to its implications for food security, inclusive rural development, and firm competitiveness. Agri-food supply chains are characterized by product perishability, quality variability, seasonality, and fragmented production by numerous smallholder farmers. These features create

coordination challenges, transaction costs, and risks that can hinder both efficiency and equity along the chain.

The processing tomato industry is a particularly suitable case for examining these issues. Processing tomatoes require tight coordination between farmers and processors regarding planting schedules, quality specifications, and delivery timing. Perishability and quality sensitivity heighten the importance of reliable relationships, effective information sharing, and risk management. Globally, leading production regions such as California, Italy, and China have developed sophisticated supply chain coordination mechanisms and technical support systems that enable high yields and consistent quality standards.

In Thailand, the processing tomato sector has developed since the 1980s, particularly in the northeastern region. Tao Ngoi district in Sakon Nakhon Province and surrounding areas have emerged as the country's tomato belt, where processing facilities provide market outlets for thousands of smallholder farmers under contract farming arrangements. Despite this long history, empirical research providing systematic and quantitative evaluation of supply chain performance in this sector remains scarce. Existing studies on contract farming and vertical coordination in Thai agriculture tend to focus on institutional arrangements or farm-level profitability, rather than on a comprehensive, multi-dimensional assessment of supply chain performance.

This study addresses this gap by examining the following research questions: (1) How does the processing tomato supply chain in Upper Northeastern Thailand perform across multiple dimensions of relational, operational, and economic performance? (2) Which specific performance gaps constrain the competitiveness and resilience of the supply chain? (3) What policy and managerial interventions are needed to strengthen coordination and support smallholder integration into modern agri-food value chains?

Building on transaction cost economics and the resource-based view of the firm (Barney 1991; Teece 2007), we conceptualize supply chain performance as a multi-dimensional construct that encompasses information sharing and joint planning, resource and benefit allocation, trust and commitment, delivery performance, flexibility, risk management, traceability, product quality, and cost and returns. We then operationalize this framework through 56 coded indicators and apply it to a sample of 120 contracted farmers in Upper Northeastern Thailand during the 2023–2024 production season.

The study contributes to the literature in three ways. First, it develops and applies a comprehensive performance measurement framework (Ramos et al. 2022) tailored to a developing country agri-food supply chain. Second, it combines perceptual measures with quantitative indicators, including technical efficiency estimated via stochastic frontier analysis, to provide a nuanced diagnosis of performance gaps. Third, it offers policy-relevant insights for upgrading the processing tomato supply chain and enhancing smallholder participation in higher-value markets.

Literature review

Transaction cost economics and contract farming

Transaction cost economics (TCE) posits that economic actors choose governance structures—markets, hierarchies, or hybrids—to minimize the combined costs of production and transactions, particularly under conditions of asset specificity, uncertainty, and frequency (Williamson 1979, 2008). In agriculture, contract farming is often viewed as a hybrid governance form that reconciles the need for coordinated quality and timing with the flexibility of market-based exchange.

Processing tomato production involves several sources of transaction costs: crop-specific investments, volatile input and output prices, and quality-dependent pricing schemes. Contract farming aims to mitigate these costs by specifying quality standards, delivery schedules, and support services (Hobbs and Young 2000; Bijman et al. 2011). However, the effectiveness of such arrangements depends critically on the relational quality between farmers and processors—particularly trust, commitment, and perceptions of fairness.

Supply chain performance measurement in agri-food systems

The Supply Chain Operations Reference (SCOR) model version 14.0 provides a widely used framework for measuring supply chain performance based on processes such as plan, source, transform, order, fulfill, return, and orchestrate (Akkawuttiwanich and Yenradee 2018; Lima-Junior and Carpinetti 2019). While SCOR has been applied across multiple industries, its direct application to agri-food chains is limited by the sector's unique characteristics.

The SCOR model has undergone significant evolution, with version 14.0 representing a paradigm shift in supply chain performance measurement. SCOR v14.0, released in 2022 as part of the SCOR Digital Standard, restructures the traditional six processes into seven major management processes: Plan, Source, Transform (expanded from Make), Order, Fulfill (split from Deliver), Return, and Orchestrate (Nguyen 2024). A critical advancement in SCOR v14.0 is the integration of sustainability performance attributes alongside traditional resilience attributes (Reliability, Responsiveness, Agility) and economic attributes (Cost, Profit, Assets Management).

Agri-food supply chain performance can be assessed along categories such as efficiency, flexibility, responsiveness, and food quality (Aramyan et al. 2007; Moazzam et al. 2018). More recent work emphasizes the importance of relationship quality—particularly trust, commitment, and information sharing—in driving supply chain performance and resilience. These approaches suggest that comprehensive performance measurement (Ramos et al. 2022) must integrate relational, operational, and economic dimensions.

Trust, information sharing, and relationship quality

Trust and commitment are central constructs in the relationship marketing literature (Morgan and Hunt 1994; Kwon and Suh 2004). In supply chains, trust reduces the need for costly monitoring and enforcement, while commitment encourages partners to invest in relationship-specific assets and joint problem-solving (Cao and Zhang 2011; Ding et al. 2014). Information sharing enhances coordination by reducing uncertainty, facilitating joint planning, and enabling faster responses to disruptions.

In agri-food supply chains involving smallholder farmers, power asymmetries between large buyers and fragmented suppliers can undermine relationship quality and limit information exchange (Gorton et al. 2015; Lees et al. 2020). These dynamics are particularly relevant for contract farming schemes, where farmers may perceive limited bargaining power and unequal allocation of risks and benefits.

Technical efficiency in developing country agriculture

Technical efficiency analysis using frontier methods has become standard in evaluating agricultural performance in developing countries (Battese 1992; Coelli 1995). Meta-analyses suggest that average technical efficiency typically ranges between 60% and 80%, indicating substantial scope to increase output with existing input levels (Bravo-Ureta et al. 2007). Determinants of efficiency often include farmer education, access to extension, credit, and organizational membership (Bravo-Ureta and Pinheiro 1993).

Conceptual framework and performance dimensions

Drawing on the above literature, we conceptualize supply chain performance as a multi-dimensional construct encompassing both relational (information sharing, trust, allocation fairness) and operational/economic (delivery, flexibility, risk management, quality, cost and returns) dimensions. We operationalize this framework through 56 indicators grouped into nine dimensions. These indicators capture both perceptual assessments and quantitative measures such as yields, costs, defect rates, and traceability capability.

International comparative framework for processing tomato supply chains

Understanding supply chain performance in a developing country context requires benchmarking against both advanced and comparable economies. The processing tomato industry provides valuable cross-regional comparisons due to its global distribution and the availability of efficiency studies across diverse institutional contexts.

European supply chain models

The European Union represents approximately 15% of global processing tomato production, with Italy (55.4%), Spain (25%), and Portugal (12%) dominating regional output (European Commission 2022). The Italian processing tomato sector has undergone significant restructuring since the 2000s, characterized by the establishment of Inter-branch Organizations (IBOs) that coordinate relationships between farmers and processors (Čechura et al. 2024).

Recent stochastic frontier analysis of the Italian tomato supply chain reveals mean technical efficiency of 81.2% at the farm level and 77.6% at the processing stage (Čechura et al. 2021). The Northern Italian supply chain, centered in Emilia-Romagna, encompasses 39,000 hectares across 2,000 producers organized into 15 Producer Organizations (Oppla 2022).

Technical efficiency in developing countries

Studies of tomato production efficiency in developing countries reveal considerable heterogeneity. In Ethiopia, Asfaw (2021) estimated mean technical efficiency of 80.9% among smallholder tomato producers. A more recent study in Northern Ethiopia found lower mean technical efficiency of 68% (Tesfay et al. 2024). Contract farming arrangements have been studied extensively across Asia and Africa. Mishra et al. (2018) found that contract farming through cooperatives in Nepal's tomato sector had positive and significant impacts on profits and yield.

[Insert Table 1 Here]

Methodology

Study area

The empirical analysis focuses on the processing tomato production zones in Upper Northeastern Thailand, particularly in Sakon Nakhon, Nong Khai, Buengkan and Nakhon Phanom provinces. This region has been a center of processing tomato production since the 1980s, when processing factories were established to provide market access for smallholder farmers. The area accounts for approximately 30,000 rai (about 4,800 hectares) of processing tomato cultivation, representing roughly 75% of Thailand's total tomato production.

Sampling and data collection

A multi-stage sampling procedure was employed. First, districts with substantial processing tomato cultivation and active contracts with processors were purposively selected. Second, villages participating in contract farming schemes were identified in collaboration with processors and local agricultural agencies. Third, within each selected village, contracted farmers were randomly selected proportional to the size of the contracted farmer population.

In total, 120 contracted farmers were interviewed between December 2023 and February 2024 using a structured questionnaire administered by trained enumerators. The survey instrument included sections on socio-economic characteristics, production practices, perceptions of supply chain relationships, operational performance, risk management, traceability, and economic outcomes.

Survey instrument and measures

The measurement items were adapted from established supply chain performance frameworks and the literature on trust, commitment, and information sharing, and then tailored to the Thai processing tomato context. Perceptual indicators were measured using 5-point Likert scales (1 = strongly disagree/very low, 5 = strongly agree/very high). Economic indicators were collected in Thai Baht (THB), kilograms, and percentages. The questionnaire was pre-tested with 15 stakeholders in a neighboring area. The internal consistency reliability was acceptable, with an overall Cronbach's alpha of 0.8611.

[Insert Table 2 Here]

Analytical methods

Integrated performance measurement framework

This study develops an integrated analytical framework that combines two complementary methodological approaches: (1) a SCOR-based multi-dimensional performance measurement system adapted for agri-food supply chains, and (2) stochastic frontier analysis for technical efficiency estimation. This integration addresses a gap in the supply chain performance literature, which has largely treated operational performance metrics and production efficiency analysis as separate domains (Aramyan et al. 2007; Bravo-Ureta et al. 2007).

Stochastic frontier analysis specification

Technical efficiency was estimated using a stochastic production frontier model following the approach of Battese and Coelli (1995). The model specification is:

$$ln(Y_i) = \beta_0 + \Sigma\beta_j\, ln(X_{ij}) + v_i - u_i$$

where Y_i represents tomato output for farm *i*; X_{ij} denotes the *j*-th input (land, labor, seeds, fertilizer, pesticides, water); v_i is a symmetric random error capturing measurement error and stochastic shocks; and $u_i \geq 0$ is the non-negative inefficiency term assumed to follow a truncated normal distribution (Kumbhakar et al. 2015; Čechura et al. 2024; Greene 2008).

Results

Information sharing and joint planning

The information sharing and joint planning dimension reveals substantial coordination gaps. While efforts to create opportunities for information exchange are at a moderate level (ISP1 = 3.10 ± 1.00), key indicators of deeper collaboration score low. Joint decision-making (ISP7 = 2.08 ± 1.09) and joint problem-solving (ISP8 = 1.77 ± 1.11) are particularly weak. Only about 40.45% (± 25.01%) of problems are reported as being effectively resolved jointly (ISP9), suggesting that most production and marketing challenges are handled unilaterally.

Resource and benefit allocation

Resource and benefit allocation patterns exhibit notable asymmetries. Shared resource utilization is very low (RBA1 = 1.49 ± 0.76), indicating limited use of cooperative arrangements for inputs, equipment, or services. Although farmers report high freedom in trading and using services (RBA7 = 4.41 ± 0.80), their perceived opportunity and ability to negotiate (RBA8 = 2.46 ± 0.92) is relatively limited. The perceived command power of partners (RBA9 = 3.49 ± 0.89) suggests that processors hold significant leverage in specifying contractual terms.

Trust and commitment

Trust and commitment indicators show a nuanced pattern. Farmers express high trust in product and service quality (TC1 = 4.22 ± 0.71) and delivery time (TC3 = 4.09 ± 0.75), indicating that basic exchange functions are reliably fulfilled. However, trust in financial matters (TC5 = 3.21 ± 1.00) and in exchanged information (TC6 = 2.79 ± 0.80) is lower. This pattern suggests that while operational aspects of the relationship function adequately, uncertainty remains around financial transparency and information reliability.

Delivery performance and flexibility

Delivery performance is mixed. Transportation time relative to standard expectations is rated favorably (DP1 = 3.78 ± 0.86), and the frequency of late deliveries is relatively low (DP2 = 1.60 ± 0.82). However, the average waiting time for produce collection (DP3 = 6.53 ± 6.05 hours) is substantial. Flexibility indicators show that accuracy in determining harvest dates is high (FL1 = 4.12 ± 0.69), while accuracy in estimating raw material quantities in the field is low (FL2 = 1.12 ± 1.71).

Risk management and traceability

Risk management emerges as a pronounced weakness. Farmers report very low frequency of formal risk assessment (RM1 = 1.34 ± 0.58), despite perceiving risk levels as high (RM2 = 4.10 ± 0.70). Traceability systems are underdeveloped with recording efficiency low (TR1 = 2.03 ± 0.89) and traceability testing capability averaging only 31.13% (TR2), substantially below the comprehensive traceability requirements increasingly demanded by modern food safety regulations (Aung and Chang 2014; FDA 2022).

Product quality performance

Product quality indicators reveal moderate performance with significant scope for upgrading. The good-to-defective fruit ratio is 81.63% (± 8.76), implying that nearly one-fifth of production is lost to defects (PQ5 = 18.37% ± 8.76). The average number of fruits per kilogram (PQ1 = 18.51 ± 3.70), per plant (PQ2 = 62.03 ± 12.01), as well as average fruit weight per plant (PQ3 = 3.59 ± 1.76 kg) and per fruit (PQ6 = 57.54 ± 24.90 g), show substantial variability.

Economic performance

Economic indicators confirm that processing tomato production is generally profitable for contracted farmers. Average production cost is 2,487.50 USD/hectare (CR1), while profit per hectare averages 3,075.60 USD (CR3). The break-even yield is 23.22 tonnes/hectare (CR4), and the average yield of 49.29 tonnes/hectare provides a comfortable margin above this threshold. The estimated return on investment is 34.27% (CR6). However, yield levels lag behind those in leading global production regions, where processing tomato yields typically range from 70 to 80 tonnes/hectare or higher (FAO 2024; Morning Star Company 2024).

Technical efficiency

Stochastic frontier analysis indicates an average technical efficiency of 69.10%, which falls within the range commonly reported for developing country agriculture. This implies that, on average, farmers could increase output by approximately 31% with existing input levels if they adopted best-practice production techniques. Factors such as farmer experience, extension contact, and involvement in farmer organizations are associated with higher efficiency.

Discussion

Coordination and governance challenges

The empirical findings are consistent with TCE predictions regarding hybrid governance structures under conditions of asset specificity and uncertainty. Contract farming provides a framework for vertical coordination, but the low levels of joint planning, problem-solving, and decision-making indicate that governance remains largely transactional rather than collaborative. Limited collaborative mechanisms increase transaction costs associated with information asymmetries, production mismatches, and dispute resolution (Chen and Paulraj 2004).

Relationship quality and information sharing

The differentiated trust profiles observed—high trust in technical and delivery performance but lower trust in financial transparency and information—highlight the multidimensional nature of relationship quality (Xiao et al. 2010). Reliable technical exchanges are necessary but not sufficient for sustainable partnerships. Without stronger trust in financial arrangements and shared information, both parties may underinvest in relationship-specific assets and joint innovations.

Competitiveness gaps and technical efficiency

Yield and efficiency results reveal significant upgrading potential. The average technical efficiency of 69.10% and yields around 49 tonnes/hectare indicate that considerable productivity gains are possible through improved agronomic practices, input use, and extension services. This is crucial for narrowing the competitiveness gap with leading producers while maintaining cost-effective raw material supply for processors (Rosset et al. 1999).

Risk management, traceability, and market access

The weak risk management and traceability systems observed pose serious challenges for long-term competitiveness (Zhong et al. 2024; Zhao et al. 2024). As food safety regulations tighten and buyers increasingly demand verifiable quality and sustainability attributes, processors will require more robust farm-level documentation and traceability systems. Strengthening risk management and traceability will likely require investments in digital tools (Belhadi et al. 2024), capacity building for farmers, and clear incentives for record-keeping.

Policy implications

Based on our empirical results and international comparisons, we propose the following policy recommendations. First, strengthening institutional coordination mechanisms: the European experience, particularly Italy's Inter-branch Organizations, demonstrates that formal coordination structures can reduce transaction costs and improve supply chain performance (Čechura et al. 2024). For developing countries, this implies supporting the formation and capacity building of Producer Organizations.

Second, investing in extension services and technical capacity: the technical efficiency gap between Thailand (69.1%) and leading producers like Italy (81.2%) reflects differences in extension service quality, farmer training, and technology adoption. Third, developing inclusive financial mechanisms: low access to credit (RBA3 = 2.14) constrains smallholder investment in productivity-enhancing technologies. Fourth, building traceability and quality management systems: the low traceability capability (31.13%) poses barriers to accessing premium domestic and export markets. Fifth, promoting fair and transparent contract arrangements: the perceived power asymmetries (RBA9 = 3.49) and limited negotiation ability (RBA8 = 2.46) suggest that contract farming arrangements may not optimally distribute risks and benefits.

Implications for regional agricultural development

For the ASEAN region and broader Southeast Asian context, Thailand's processing tomato sector can serve as a model for regional agricultural value chain development. The yield gap between Thailand (49 tonnes/hectare) and international benchmarks (70–80 tonnes/hectare) represents both a challenge and an opportunity. Closing this gap would significantly enhance smallholder incomes and sector competitiveness.

Conclusions

This study develops and applies a comprehensive, multi-dimensional framework for assessing supply chain performance in a developing country agri-food context. By integrating relational, operational, and economic dimensions—including technical efficiency estimated via stochastic frontier analysis—the framework provides a nuanced diagnosis of performance gaps in Thailand's processing tomato supply chain.

The key findings reveal that while the supply chain is economically viable, with positive returns on investment and yields above break-even thresholds, significant coordination gaps, underdeveloped risk management and traceability systems, and technical inefficiencies constrain the sector's competitiveness and resilience. The average technical efficiency of 69.10% and yields around 49 tonnes/hectare indicate substantial scope for productivity improvements.

The study contributes to both academic understanding and practical policy development by demonstrating how integrated performance measurement can identify specific bottlenecks and inform targeted interventions. The policy recommendations—strengthening institutional coordination, investing in extension services, developing inclusive financial mechanisms, building traceability systems, and promoting fair contract arrangements—provide a roadmap for upgrading the processing tomato supply chain and, more broadly, for enhancing smallholder integration into modern agri-food value chains.

Future research should extend this framework to panel data analysis, incorporate processor-level perspectives, and explore the impact of digital technologies on supply chain coordination and smallholder productivity.

Declarations

Competing interests

The authors declare that they have no competing interests.

Ethics approval and consent to participate

This study involved surveys with adult participants who provided informed consent prior to their participation. No experiments on human subjects or animals were conducted.

Consent for publication

Not applicable.

Authors’ information

[Authors’ information removed for peer review]

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Author Contribution

TR conceptualized the study, designed the methodology, collected and analyzed the data, and wrote the original draft. KP contributed to methodology development and data analysis. TL contributed to data collection and fieldwork coordination. All authors read and approved the final manuscript.

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Data Availability

The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

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Tables

Table 1: International Comparison of Processing Tomato Supply Chain Performance

Region/Country	**Technical Efficiency (%)**	**Yield** ton/hextare	**Governance Model**	**Source**
Italy (N. Italy)	81.2	70-80	Inter-branch Org.	Čechura et al. (2021)
USA (California)	85-90*	90-100	Vertical integration	Morning Star (2024)
Ethiopia	68-80.9	15-25	Spot market	Asfaw (2021)
Nepal	N/A	20-30	Cooperative CF	Mishra et al. (2018)
Thailand (This study)	**69.1**	**49**	**Contract farming**	**Current study**

*Note: *Estimated. CF = Contract Farming. t/ha = tonnes per hectare.*

Table 2: Supply Chain Performance Indicators and Descriptive Statistics

Performance Dimension	Code	Indicator	Mean ± SD
Information Sharing and Joint Planning	ISP1	Level of effort to create opportunities for information exchange	3.10 ± 1.00
	ISP2	Level of experience sharing	2.61 ± 0.93
	ISP3	Level of information exchange	2.91 ± 0.76
	ISP4	Level of clarity and understanding of information	2.79 ± 0.94
	ISP5	Frequency of providing erroneous information	2.53 ± 1.44
	ISP6	Level of joint planning	2.34 ± 1.27
	ISP7	Level of joint decision-making	2.08 ± 1.09
	ISP8	Level of joint problem-solving	1.77 ± 1.11
	ISP9	Percentage of problems effectively resolved jointly (%)	40.45 ± 25.01
	ISP10	Level of cooperation in forming groups	2.11 ± 1.10
	ISP11	Frequency of farmer visits by partners	2.08 ± 1.22
Resource and Benefit Allocation	RBA1	Level of shared resource utilization	1.49 ± 0.76
	RBA2	Ratio of shared input support to output value	0.54 ± 0.56
	RBA3	Level of support for access to financing	2.14 ± 0.78
	RBA4	Level of purchasing goods or using services	3.83 ± 0.71
	RBA5	Level of interdependence	2.23 ± 1.00
	RBA6	Level of adaptability	4.06 ± 0.98
	RBA7	Level of freedom in trading or using services	4.41 ± 0.80
	RBA8	Level of opportunity and ability to negotiate	2.46 ± 0.92
	RBA9	Level of partner's command power	3.49 ± 0.89
	RBA10	Level of risk of being exploited or taken advantage of	2.50 ± 0.96
	RBA11	Level of encountering inferior goods or services	1.95 ± 0.90
	RBA12	Level of speed in delivery or receiving services	3.60 ± 0.89

Performance Dimension	Code	Indicator	Mean ± SD
Trust and Commitment	TC1	Level of trust in product/service quality as agreed	4.22 ± 0.71
	TC2	Level of trust in product/service quantity as agreed	3.81 ± 0.90
	TC3	Level of trust in delivery time as agreed	4.09 ± 0.75
	TC4	Level of trust in trading criteria and conditions	3.75 ± 0.76
	TC5	Level of trust in financial matters as agreed	3.21 ± 1.00
	TC6	Level of trust in exchanged information	2.79 ± 0.80
	TC7	Level of commitment fulfillment	3.70 ± 0.78
Delivery Performance	DP1	Transportation time compared to standard time (hours)	3.78 ± 0.86
	DP2	Frequency of late deliveries (times)	1.60 ± 0.82
	DP3	Waiting time for produce collection (hours)	6.53 ± 6.05
Flexibility	FL1	Accuracy in determining harvest date	4.12 ± 0.69
	FL2	Accuracy in estimating raw material quantity in the field	1.12 ± 1.71
	FL3	Raw material quality flexibility rate (%)	7.85 ± 2.47
	FL4	Payment cycle for raw materials (days)	13.89 ± 4.08
	FL5	Frequency of late payment for raw materials (times)	1.16 ± 0.61
Risk Management	RM1	Frequency of risk assessment	1.34 ± 0.58
	RM2	Level of perceived risk	4.10 ± 0.70
	RM3	Level of response when risk factors are identified	4.23 ± 2.27
Traceability	TR1	Recording efficiency	2.03 ± 0.89
	TR2	Traceability testing capability (%)	31.13 ± 0.46
Product Quality	PQ1	Number of fruits per kilogram (fruits)	18.51 ± 3.70
	PQ2	Number of fruits per plant (fruits)	62.03 ± 12.01
	PQ3	Fruit weight per plant (kg)	3.59 ± 1.76

Performance Dimension	Code	Indicator	Mean ± SD
	PQ4	Good to defective fruit ratio (%)	81.63 ± 8.76
	PQ5	Total defect rate (%)	18.37 ± 8.76
	PQ6	Average weight per fruit (g)	57.54 ± 24.90
Cost and Returns	CR1	Production cost per hectare (USD)	2,487.50
	CR2	Yield per hectare (tones)	49.29
	CR3	Profit per hectare (USD)	3,075.60
	CR4	Break-even yield (tones/ hectare)	23.22
	CR5	Transportation cost (USD/ton-km)	0.017
	CR6	Return on investment (%)	34.27
	CR7	Raw material procurement cost (USD/tones)	4.72

Note: The complete table with all 56 indicators is provided in the supplementary Excel file. Perceptual indicators measured on 5-point Likert scale (1 = strongly disagree/very low to 5 = strongly agree/very high). Economic indicators (CR1-CR7) reported in actual values (USD, kg, percentages). 1 rai = 0.16 hectares.

Indicator Code Legend:

ISP = Information Sharing and Joint Planning (11 indicators)

RBA = Resource and Benefit Allocation (12 indicators)

TC = Trust and Commitment (7 indicators)

DP = Delivery Performance (3 indicators)

FL = Flexibility (5 indicators)

RM = Risk Management (3 indicators)

TR = Traceability (2 indicators)

PQ = Product Quality (6 indicators)

CR = Cost and Returns (7 indicators)

Figures

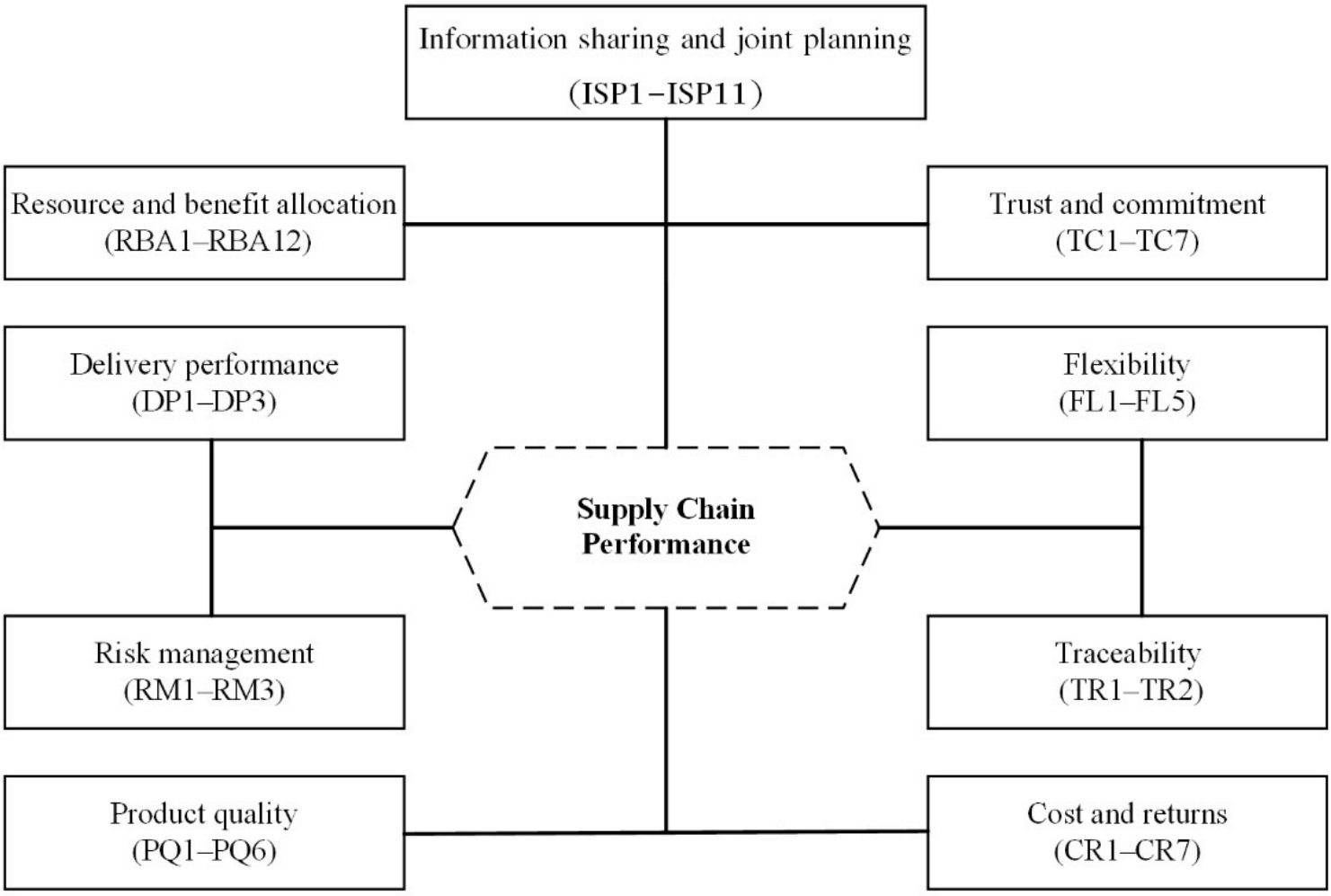


Figure 1

Supply chain performance dimensions