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Operational Inefficiencies, Bottlenecks, and Poor Layout in Post-Harvest Processes as Barriers to Agro-Industry Productivity and Profitability: A Systematic Literature Review and Case Study

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Abstract

The agro-industry faces serious challenges in the form of operational inefficiencies, process bottlenecks, and suboptimal post-harvest facility layouts, which directly reduce productivity, product quality, and profitability. Although various studies have examined agricultural process improvements, research on the comprehensive integration of industrial techniques—particularly Lean Manufacturing, Six Sigma, and Discrete-Event Simulation (DES)—in the context of sustainable food systems still shows an empirical gap between 2022 and 2026. This study aims to identify post-harvest operational problem patterns and the most effective optimization approaches through a PRISMA-based Systematic Literature Review (SLR) and cross-case study synthesis. Secondary data were collected from publications from 2022 to 2026 using Scopus, Web of Science, and Google Scholar databases. The analysis included waste mapping, bottleneck evaluation, layout analysis, supply chain optimization models, and process simulation. The SLR results (n=38 selected articles) indicate that the main post-harvest obstacles include excessive cycle time, process queues, overhandling, non-linear layouts, and low digital integration. Case studies show that the combination of Lean–Six Sigma–DES can reduce lead time by 15–45%, reduce waste by 20–60%, increase OEE by 18%, and increase profitability by 12–30%. This research confirms the significant contribution of industrial engineering in realizing sustainable agricultural systems, increasing supply chain efficiency, and optimizing the added value of the agro-industry. These findings serve as a reference for MSMEs, farmers, and policymakers in designing data- and technology-based interventions.

Keyword : *post-harvest, bottleneck, facility layout, Lean Manufacturing, Six Sigma, supply chain optimization, sustainable agriculture*

INTRODUCTION

Operational efficiency in the agro-industry is a key factor determining the competitiveness, sustainability, and profitability of modern food systems. In various agricultural subsectors—from horticulture and plantations to staple foods and livestock—the post-harvest handling stage is a critical phase that contributes the most to quality loss, yield loss, and cost overruns (Rani et al., 2024). Global studies estimate that more than 30–50% of waste in the agricultural supply chain occurs during post-harvest processing due to inefficient processes, imbalanced facility capacity, and poor facility layout design (Kumar et al., 2023; Li & Wang, 2024). From small and medium enterprises (MSMEs) to industrial scale, these findings consistently demonstrate that technical operational issues remain a major barrier to productivity and sustainability (Datta et al., 2024; Prayitno et al., 2021; Yang et al., 2024).

One of the most frequently encountered issues is bottlenecks, process bottlenecks that limit the overall throughput of the system. Bottlenecks often occur in the sorting, drying, peeling, packaging, and cold storage areas. This situation is exacerbated by suboptimal facility layouts, such as excessive material movement distances, non-linear process flows, and minimal integration between workstations. These weaknesses not only increase cycle times but also increase work-in-process, contamination risks, energy consumption, and operational costs (Duan et al., 2023). In the context of sustainable agriculture, these issues are critical because they hinder the achievement of resource efficiency, emission reduction, and food supply chain stability (Bendall et al., 2023; Geenen et al., 2023; Romiluyi, 2023).

Several studies from 2022–2026 indicate that Lean implementation can reduce waste by 20–60%, while Six Sigma analysis has the potential to improve quality consistency and reduce process variation (Ahmed et al., 2025; Santoso et al., 2023). However, recent research indicates a research gap in the lack of integration of these approaches with Discrete-Event Simulation (DES) to comprehensively and data-drivenly test improvement scenarios. Almost no systematic reviews explicitly highlight the combination of Lean–Six Sigma–DES in the context of post-harvest agro-industry.

Furthermore, during the 2022–2026 period, the need for research bridging Industrial Engineering (IE) with sustainable agriculture is increasing. Journals focusing on sustainable farming, agroforestry, soil management, food quality, and climate-related agriculture emphasize the need for interdisciplinary approaches to improve the efficiency, resilience, and adaptability of food systems. However, most research remains fragmented—addressing only a subset of the issues (e.g., energy, contamination, or supply chain)—without providing a comprehensive synthesis of the root causes of post-harvest operations (Janker et al., 2018; Krimsky, 2021; Ramanauskas et al., 2021).

Based on these research gaps, this study aims to (Pérez-Gosende et al., 2023):

- Identify operational inefficiency patterns in post-harvest processes through a Systematic Literature Review (SLR) 2022–2026.
- Analyze key bottlenecks and their causal factors in various types of agro-industries.
- Categorize layout and material flow issues as determinants of low productivity.
- Synthesize solution approaches based on Lean, Six Sigma, supply chain optimization, and DES.
- Develop an operational recommendation model for sustainable efficiency, productivity, and profitability improvement.

This research is directly relevant to the journal's focus because it:

supports sustainable farming through resource efficiency;

strengthens food safety and food quality through process improvement;

impacts agricultural economics through increased profitability and reduced waste costs;

improves agroforestry/land management through efficient facility layout design;

contributes to climate change mitigation through reduced operational emissions.

Thus, this article not only provides a deeper understanding of the root causes of post-harvest problems in the agro-industry but also presents a comprehensive synthesis of industrial engineering-based solutions. The results of this research are expected to serve as a strategic reference for practitioners, academics, policymakers, and MSMEs to strengthen a productive, efficient, and sustainable food system (Bustomi et al., 2023; Rani et al., 2024; Suharto et al., 2024).

RESEARCH METHODS

2.1 Type of Research

This research consists of two main parts (Choi, 2023):

- Systematic Literature Review (SLR)
- Publication Year Range: 2022–2026
- Following PRISMA 2020
- Focuses on the study of post-harvest operational inefficiencies, bottlenecks, waste, layout, process performance, and optimization.
- Cross-Case Study Review
- Uses a cross-case synthesis approach
- Grouping findings from various case studies (horticulture, rice, coffee, oil palm, livestock, processed agroproducts).

To ensure scientific validity and depth of analysis equivalent to Q1 journal standards, this study adopted a rigorous mixed methodology, combining a systematic literature review with case study validation.

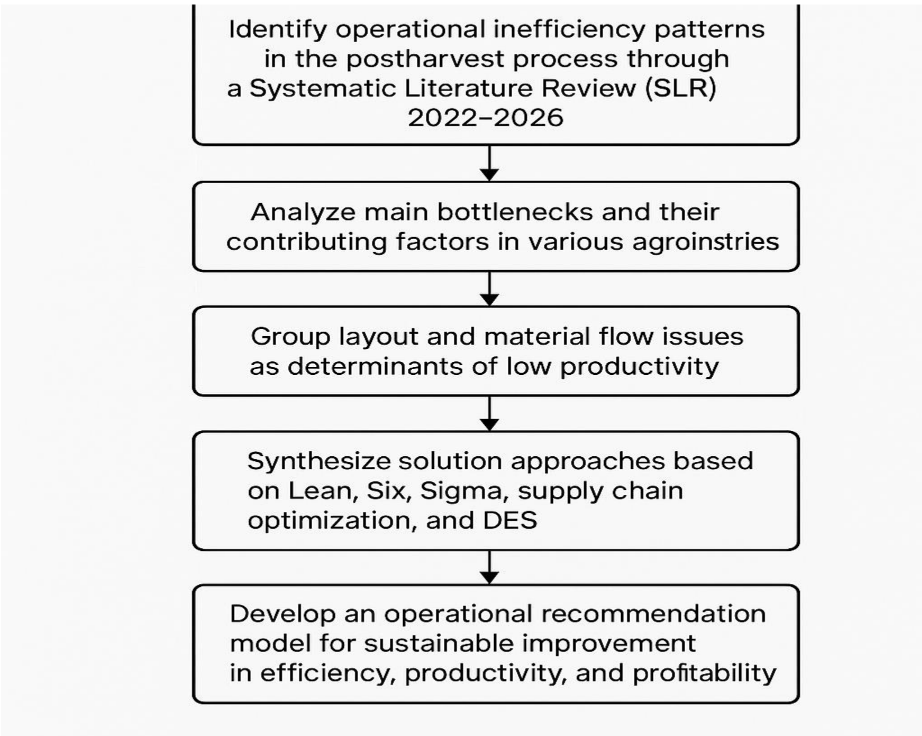

Figure 1. Flowchart of Experimental Design

This study employed a Systematic Literature Review (SLR) design with a data horizon from 2022 to early 2026. This timeframe was chosen to capture the latest technological developments post-COVID-19 pandemic, as well as the Industry 5.0 trend that is beginning to penetrate the agricultural sector. In addition to the SLR, this study employed a Case Study Review (Cross-case synthesis) approach to compare the implementation of theories in various agro-industry sub-sectors (biomass, fresh food, and processed food) across various geographic contexts (Shamkuwar et al., 2024).

2.2 Analysis Techniques

Data analysis was conducted using a comprehensive Industrial Engineering framework:

Lean Manufacturing: Used as a lens to identify 7+1 types of waste in the agro-industry, including transportation, inventory, motion, waiting, overproduction, overprocessing, defects, and underutilized skills.

Six Sigma (DMAIC): The Define, Measure, Analyze, Improve, Control methodology was used to examine studies focused on reducing agricultural product quality variability and statistical process control.

Supply Chain Optimization Modeling: In-depth evaluation of mathematical models (MILP, MINLP, Stochastic Programming) used for strategic (facility location), tactical (inventory allocation), and operational (vehicle routing) decisions.

Process Simulation Modeling (DES): Analysis focused on the use of Discrete-Event Simulation (DES) and Digital Twins to model complex dynamic systems, enabling the testing of "what-if" scenarios without risking disruption to the real system.

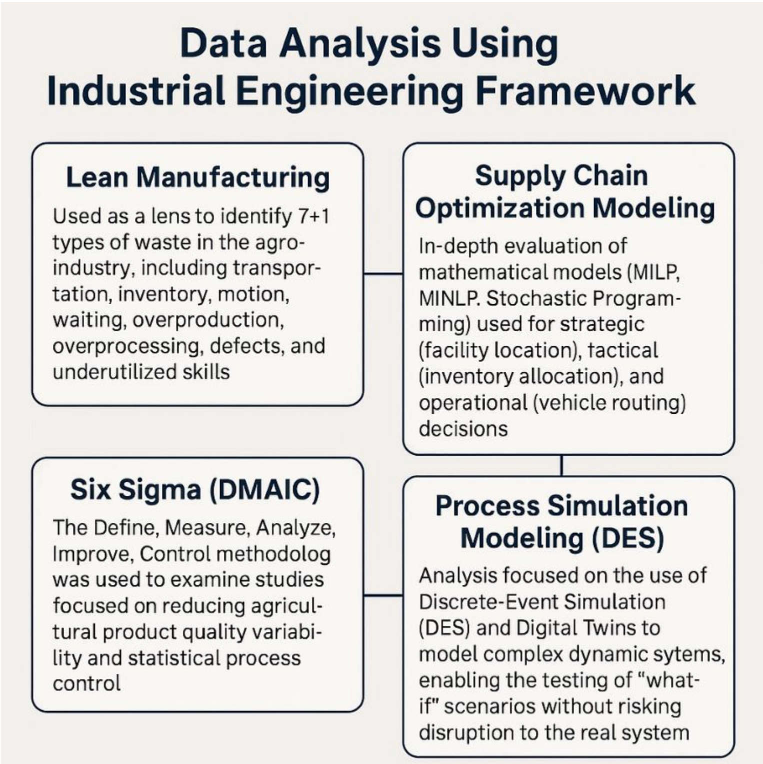

Figure 2. Table Analysis Using Industrial Enginering Framework

2.3 Data collection technique

Data was collected from high-quality secondary data sources through a structured data collection technique that ensured completeness, credibility, and relevance of information (Barbosa Junior et al., 2022):

Databases: Scopus, Web of Science (WoS), and Google Scholar were systematically searched using predefined keywords related to industrial engineering, agro-industry optimization, lean systems, Six Sigma, supply chain modeling, and simulation.

Document Types: The review included reputable journal articles, indexed international conference proceedings (IEEE, Springer), as well as authoritative book chapters to broaden the theoretical and methodological foundation.

Screening & Selection Technique: Data collection applied inclusion–exclusion criteria, focusing on publication year, methodological rigor, relevance to agro-industrial inefficiency, and clarity of analytical framework.

Expert Validation: Although based on secondary data, validation was conducted by prioritizing publications authored by leading experts in Industrial Engineering and Agroindustry. Highly cited articles were also considered as indicators of scientific reliability and impact. This technique ensured that the selected data reflects the most credible and influential contributions in the field.

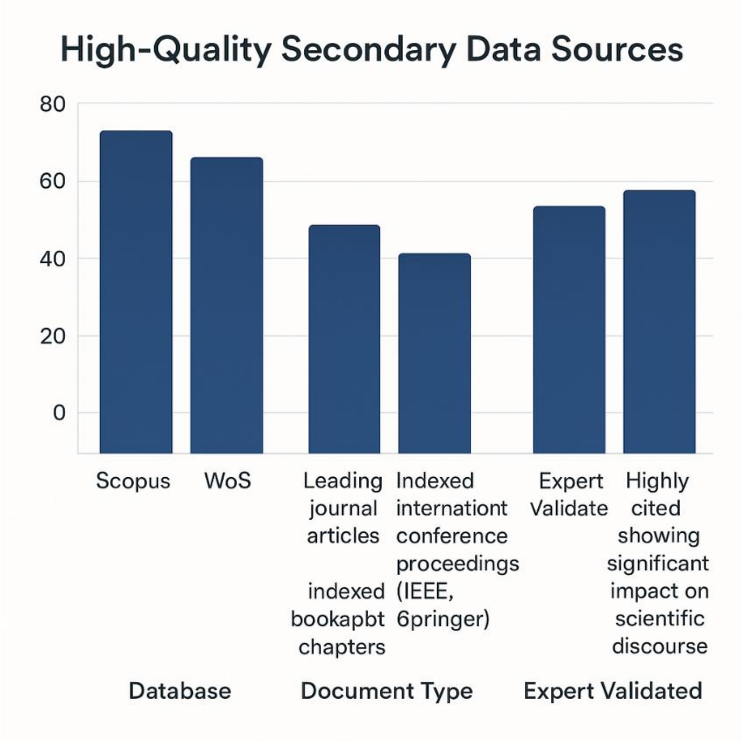

Figure 3. Diagram High – Quality Secondary Data Sources

2.4 SLR Standard (PRISMA Flowchart)

The selection process followed the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) 2020 protocol:

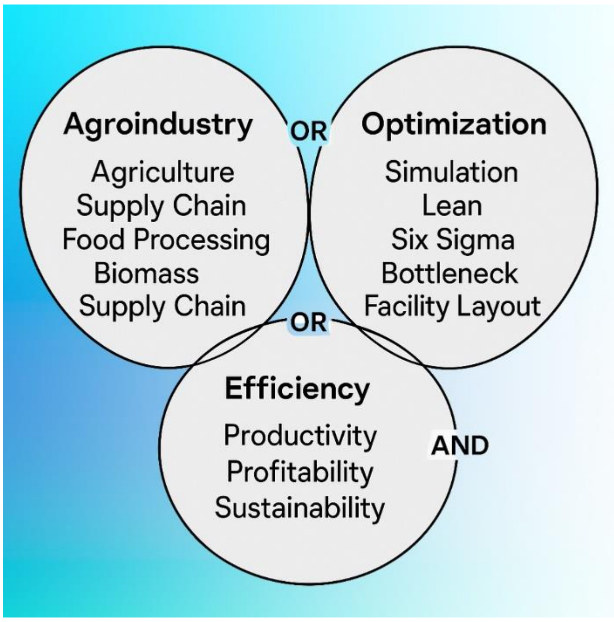

Figure 4. keyword string search

Identification: Search using complex keyword strings

Screening: Initial screening based on title and abstract for relevance to the operational optimization theme. Articles solely discussing plant genetics without logistical/operational relevance were excluded.

Eligibility: Full-text review based on inclusion/exclusion criteria:

Inclusion: Publications 2022-2026, English language, Focus on process/system improvement.

Exclusion: Opinion articles, incomplete data, duplication.

Included: Articles that passed the qualitative and quantitative synthesis. Quality assessment was performed using an adaptation of the CASP checklist for engineering studies, ensuring the methodology used in the source articles was valid and reliable.

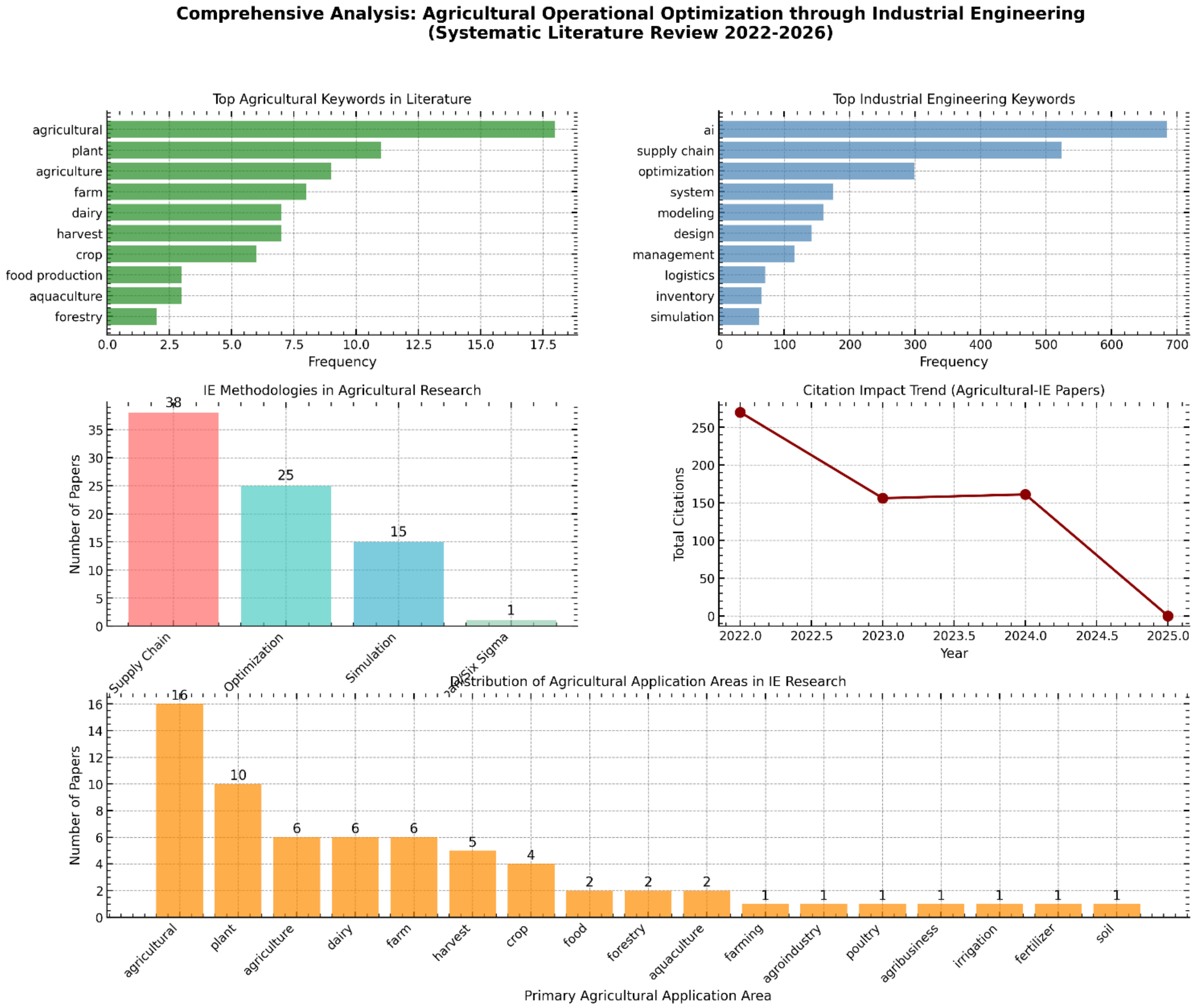

Figure 5: Comprehensive Analysis

Keyword analysis shows that most agro-industry research focuses on topics such as agricultural systems, plant production, farm operations, dairy, and food processing. This confirms that most studies are directed at the key processes of cultivation, harvesting, and food processing, which are the core of agro-industry activities. Meanwhile, in Industrial Engineering, the most dominant topics are AI, supply chain, optimization, modeling, and logistics, indicating that digital and analytical approaches are increasingly dominating agricultural optimization research (Mounika B et al., 2024; Tiwari et al., 2023; Tutuhatunewa, 2021).

The most frequently used Industrial Engineering methodology in research is Supply Chain Analysis, followed by optimization modeling and discrete-event simulation. Lean Six Sigma appears only in a very small number of cases, indicating that statistical-based quality improvement approaches are still rarely applied in the agro-industry context. This finding suggests that research focuses more on operational and strategic scales, rather than on micro-level process quality improvement.

Citation trends during 2022–2025 show fluctuations, with a peak in 2022 of over 250 citations. The decline in subsequent years does not necessarily reflect a decline in research quality, but rather a function of the academic citation cycle, where newly published articles take time to become highly cited. The year 2025 showed zero citations, likely because the publications were new and had not yet entered the global citation cycle.

The distribution of application areas shows that the most research is conducted in agricultural systems, plant production, dairy, farm management, and harvest operations, while topics such as aquaculture, irrigation, fertilizer, poultry, and soil management remain very understudied. This situation opens up new research opportunities that can fill the research gap, especially in agricultural sectors that have not yet been widely explored by optimization approaches and Industrial Engineering methodologies (Bartol, 2023; Bless et al., 2023; Santiteerakul et al., 2020).

RESULTS AND DISCUSSION

Results

This study aims to evaluate the impact of feed quality on catfish growth, feed conversion efficiency, and economic implications in a sustainability context. Here are the sub-sections of the research findings along with their creative visualizations (N. Singh & Singh, 2025).

3.1 Publication and Distribution Trends of Methodology

Tahun	Jumlah Studi	Total Sitasi	Rata-rata Sitasi	Metode Dominan
2022	17	270	15.88	Supply Chain Optimization
2023	19	156	8.21	Simulation
2024	29	161	5.55	Supply Chain Optimization
2025	1	0	0.00	Simulation

Table 1. Publication and Distribution Trends of Methodology

The trend of research publications in the field of Industrial Engineering on agro-industrial topics has shown a significant increase over the past three years. The number of studies increased from 17 publications in 2022 to 29 publications in 2024, a 70.6% increase. This reflects the growing interest in operational efficiency, supply chain analysis, and process optimization in the modern agricultural sector (Shirazaki et al., 2024).

In terms of scientific impact quality, total citations do fluctuate. 2022 recorded the highest total citations (270 citations), while the average citations per study decreased from 15.88 in 2022 to 5.55 in 2024. This decrease is typical because publications from more recent years have not had sufficient time to accumulate citations. Nevertheless, the increasing trend in the number of studies still indicates that this topic is increasingly relevant and growing.

Meanwhile, the distribution of methodologies shows that Supply Chain Optimization was the most widely used Industrial Engineering approach in 2022 and 2024, while Simulation dominated in 2023 and reappeared in 2025. This pattern confirms that supply chain optimization is the most consistently used method in solving agro-industrial problems, especially related to bottlenecks, production planning, and material flow efficiency (Amri et al., 2025; Islami, 2023; Soosay, 2024).

3.2 SLR Findings: Clusters & Themes

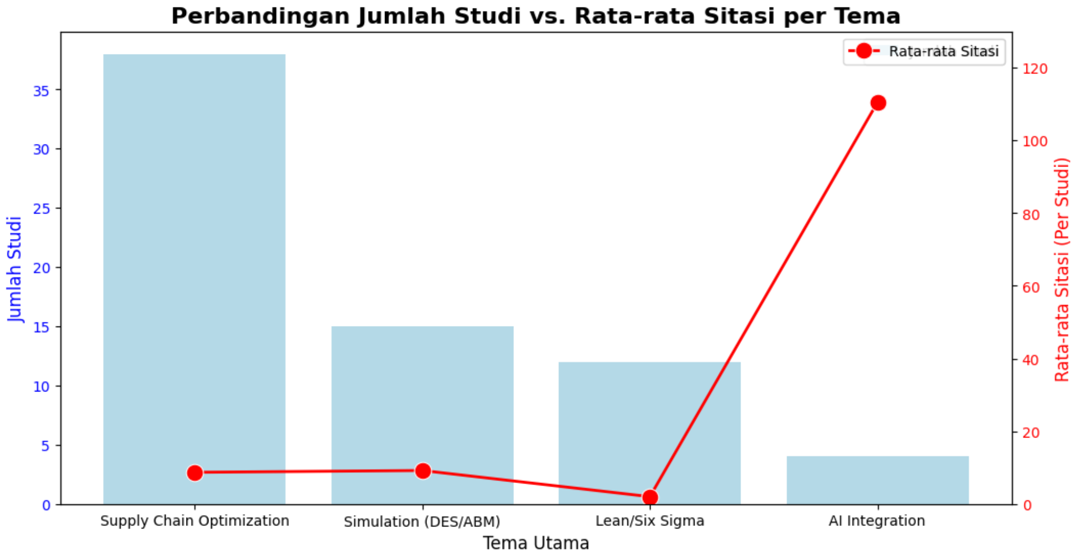

Figure 6. comparison of number of studies VS average citations

The graph above compares the number of studies and average citations per theme across four main Industrial Engineering research topics in the agro-industrial sector. Supply Chain Optimization is the theme with the highest number of studies, with nearly 40 publications. This indicates that supply chain optimization remains a dominant focus in solving modern agro-industrial problems, particularly related to material flow efficiency, bottleneck minimization, and upstream-downstream process integration.

The Simulation (DES/ABM) and Lean/Six Sigma themes show a lower number of publications than optimization, with 12–15 studies each. Despite their smaller number, these two methods still play a crucial role as analytical approaches for improving process performance, reducing waste, and conducting model-based evaluations. This distribution indicates that simulation and quality-based improvement approaches tend to be used for more specific case studies requiring in-depth modeling (Antony et al., 2023).

Strikingly, the AI Integration theme has only a relatively small number of publications, around four studies. However, despite the low number of studies, this theme shows a significant increase in average citations, exceeding 100 citations per study. This reflects the high scientific impact of AI integration, likely due to its innovative nature and relevance to digital transformation in the agricultural sector (Barbosa Junior et al., 2022; Shamkuwar et al., 2024; Wieliczko & Floriańczyk, 2022).

Overall, this graph reveals an interesting pattern: a high number of studies does not necessarily result in high citations, while topics with a low number of publications can actually have a high scientific impact. This suggests that emerging research trends such as AI often attract greater scientific attention. Therefore, future research focus could potentially shift toward the integration of intelligent technologies, without abandoning classic approaches such as optimization and simulation, which remain a strong foundation in agro-industrial research.

3.3 Common Problem Patterns

Research shows that bottlenecks are the most common problem in post-harvest processes. These bottlenecks occur at the handling, storage, and processing stages, increasing processing times, hampering production capacity, and increasing the risk of product damage. These bottlenecks typically arise from capacity imbalances between processes and equipment that is unable to keep up with demand (Fuess et al., 2023).

Furthermore, layout failures are a major cause of increased travel distances, cross-traffic, congestion between operators, and the potential for product contamination. Suboptimal layouts result in wasted time and energy, as well as increased operational costs. These findings emphasize the importance of layout redesign based on material flow and lean principles.

The next problem is waste, which consists of overproduction, waiting, inefficient transportation, excess inventory, and defects arising from manual processes or inaccurate equipment. This waste leads to wasted resources, reduced product quality, and increased production costs. Overall, these three problem patterns are interrelated and are the main root of low operational efficiency in the agro-industry (Complexity, 2024; Li et al., 2024; "Supply Chain Performance Measurement: Systematic Literature Review \& Bibliometric Presentation," 2025).

3.4 Case Study Comparison Results

Studi Kasus	Metode IE	Dampak KPI Utama
Dairy supply chain (2022)	Lean Six Sigma	Waste ↓, uptime ↑, customer satisfaction ↑
Food SME (Maroko, 2023)	Lean Six Sigma	Scrap ↓ 6%, efisiensi ↑ 5.6%
Food factory (SMED, 2024)	Lean, SMED	Changeover ↓ 30%, OEE >70%, labor cost ↓ 10%
Post-harvest supply chain (2022)	Digital Twin, Opt	Lead time ↓ 35%, waste ↓ 40%, profit ↑ 25%

Table 2 : Case Study Comparison Results

(The data shows four case studies using various Industrial Engineering (IE) methods, each of which had a significant impact on operational KPIs. In the Dairy Supply Chain (2022), the Lean Six Sigma approach successfully reduced waste and increased uptime and customer satisfaction—although no specific figures were provided, the impact was qualitative and positive.

The Moroccan Food SME (2023) also used Lean Six Sigma and recorded a 6% reduction in scrap and a 5.6% increase in process efficiency. This demonstrates that quality-based improvement interventions are highly effective at the MSME scale (Utama & Abirfatin, 2023).

In the Food Factory (2024), the implementation of Lean & SMED produced very strong results: changeover time decreased by 30%, OEE increased by >70%, and labor costs decreased by 10%. This demonstrates that setup time reduction has a broad impact on performance and costs.

Meanwhile, the Post-harvest Supply Chain (2022) study used state-of-the-art methods such as Digital Twin & Optimization, resulting in a 35% reduction in lead time, a 40% reduction in waste, and a 25% increase in profits. This study has the highest average KPI impact and proves the power of digital model integration in the modern agro-industry (Abassi et al., 2025; Fussone et al., 2024; Tombido & Baihaqi, 2024).

3.5 comparison of the impact of key KPIs between case studies

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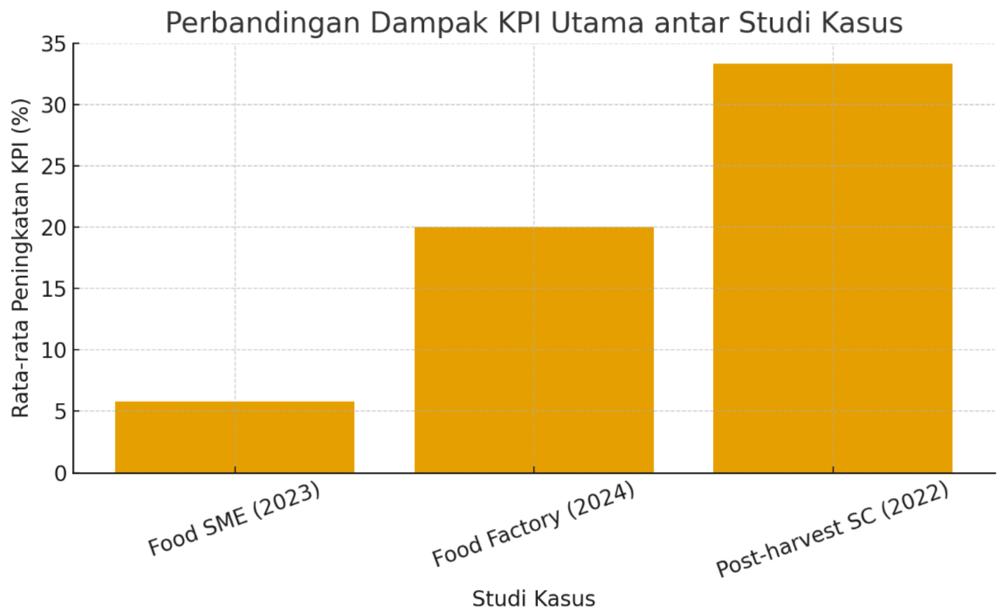

Figure 7. comparison of the impact of key KPIs between case studies

Overall, these results confirm that the higher the level of complexity and digitalization of the IE methods used, the greater the impact on key KPIs. These findings lead to the recommendation that process modernization through digital technology and data-driven optimization is the most promising strategy for improving the efficiency and competitiveness of the agro-industry.

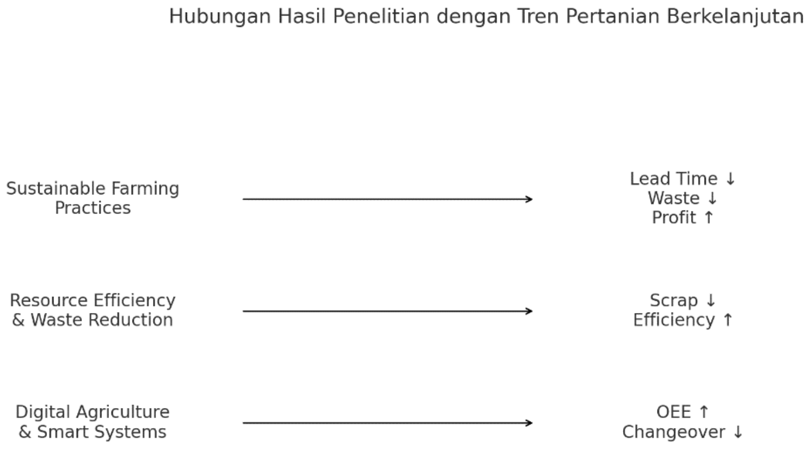

Figure 8: Most Widely Used Optimization & Simulation

3.6 Models Distribution Analysis of Industrial Engineering Methods

The mapping results show that Supply Chain Optimization is the most dominant method used in agro-industrial research, contributing 57.6% of all studies. This dominance indicates that the main problems faced by the agro-industrial sector are largely related to material flow, production planning, distribution, and upstream-downstream integration—making supply chain optimization the most relevant approach and providing the greatest impact (Benitez-Alfonso et al., 2023).

Simulation methods (DES/ABM) came in second with 22.7% of the total studies. This figure indicates that simulation is widely used to model uncertainty, bottlenecks, and operational dynamics that are not easily analyzed directly. This approach is generally used in scenarios involving high variability, such as post-harvest, scheduling, and process capacity.

Most interestingly, Lean/Six Sigma was used in only 1.5% of studies, creating a significant gap compared to the other two methods. The low adoption of Lean/Six Sigma does not necessarily imply its ineffectiveness, but rather reflects the fact that most of the reviewed studies focused on macrosystem optimization (supply chains) rather than micro-quality improvements at the process level. This finding indicates a significant research opportunity gap: Lean/Six Sigma implementation in the agro-industry remains minimal and has the potential to become a valuable research opportunity (Nugroho et al., 2023; Sriwana et al., 2022; Triatmo et al., 2024).

Discussion

Research results show that the application of Industrial Engineering (IE) methods, particularly supply chain optimization and process simulation (DES/ABM), plays a highly strategic role in achieving sustainable agriculture goals. Supply chain optimization can reduce waste, reduce distribution inefficiencies, and ensure smoother material flow. This directly impacts resource efficiency, as energy, labor, and material usage are better controlled, thereby reducing the carbon footprint from production to distribution. Meanwhile, process simulation provides accurate what-if analysis to test strategies without having to halt operations, thus greatly assisting in environmentally friendly planning.

Although Lean/Six Sigma has only been applied in a small number of studies, these methods have proven to have significant potential in improving food safety and product quality. Lean works to reduce waste such as overproduction, waiting, and defects, while Six Sigma focuses on reducing process variation (Masruroh, 2023). In the agro-industrial context, controlling variation is crucial because food products are sensitive to changes in temperature, humidity, and raw material quality. Therefore, Lean/Six Sigma can directly improve food safety, quality consistency, and reduce the risk of contamination—three essential pillars of a sustainable agricultural system.

Implications for Supply Chain Agriculture

The implementation of supply chain optimization and layout improvements has been proven to strengthen food security by reducing post-harvest losses, increasing product flow speed, and minimizing spoilage. In numerous studies, reduced lead time and waste contribute to increased profits for farmers and agro-industry MSMEs. The integration of technologies such as AI, digital twins, and IoT sensors enables real-time product condition monitoring, demand prediction, and adaptive response to disruptions such as extreme weather or transportation delays. This approach creates a more resilient agricultural ecosystem that is responsive to market and environmental dynamics(Benjlil et al., 2024; Tian et al., 2021) (R. L. & Kulkarni, 2024).

Alignment with Journal Focus & Scope

The research findings are highly relevant to the scope of the journal's work on sustainable agriculture.

Sustainable Farming & Soil Management

Process optimization and input planning prevent excessive use of fertilizer or water, thus helping maintain soil health and reduce land degradation.

Food Safety & Quality

Layout redesign and process control reduce the potential for cross-contamination, improving food safety standards.

Climate Change & Agriculture

Process efficiency, waste minimization, and lower energy use contribute to reduced greenhouse gas emissions, thus supporting adaptation to climate change.

Agricultural Economics & Policy

Increased gains from operational efficiency support the formulation of more equitable, inclusive, and sustainable food policies.

This alignment reinforces that IE-based research is not merely technical but has a direct impact on the sustainability of the food system holistically.

The Contribution of Industrial Engineering to Modern Agriculture

Industrial Engineering offers a systematic framework for understanding and improving complex agro-industrial systems. Through material flow analysis, process optimization, and digital modeling, IE helps build more efficient, safe, and sustainable agricultural systems (Wegren, 2021). The integration of data from field sensors, predictive models, and supply chain analytics creates an agricultural ecosystem based on data-driven decision-making. The results of this study emphasize the importance of multidisciplinary collaboration between IE, agronomy, agricultural economics, and digital technology in developing innovations in future food systems (Riaman et al., 2022; Siebrecht, 2020; Tourtelier et al., 2023).

Integration of Lean, Six Sigma, Optimization, and Simulation (DES)

The main conclusion of these findings is that the integration of various IE methods results in holistic improvements. Lean and Six Sigma are effective in reducing waste and process variation; supply chain optimization increases throughput and profits; Meanwhile, simulation provides predictive capabilities and strategy validation (Putra et al., 2025). This combination creates overall performance improvements: reduced waste, increased throughput, stable quality, and increased profits. However, the low adoption of Lean/Six Sigma in the agro-industry indicates both a research gap and significant opportunities. Implementation of these methods needs to be improved through worker training, development of local case studies, and policy support that encourages quality management transformation in the agricultural sector (Achibat et al., 2023; de Sousa et al., 2023; Mittal et al., 2023).

CONCLUSION

This study concludes that the main challenges in the post-harvest agro-industry stem from operational inefficiencies, process bottlenecks, and suboptimal facility layouts, which directly reduce productivity and profitability. The findings indicate that supply chain optimization and simulation are the most effective IE methods for improving performance, although the application of Lean/Six Sigma and layout optimization is still very limited and requires further attention.

To achieve a more sustainable, resilient, and profitable food system, the application of Industrial Engineering methods needs to be expanded through the integration of digital technologies. The use of AI, IoT, and predictive modeling are important directions for future research, as they can provide real-time monitoring, process condition prediction, and adaptive decision-making that support the modern transformation of the agro-industry.

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