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Postharvest Losses, Physical Traceability, and Supply Chain Efficiency of Banana (*Musa spp*.) in Lampung Province, Indonesia

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Abstract

Bananas (*Musa spp*.) are nutrient-rich natural products with climacteric characteristics, making them highly susceptible to mechanical damage and biological deterioration during postharvest handling. This study aimed to map the supply chain, evaluate physical traceability, and quantify postharvest losses of banana commodities in Lampung Province, Indonesia. The research was conducted from August 2024 to May 2025 in major production areas, namely Central Lampung, Tanggamus, and West Lampung Regencies, involving 94 farmers. Data were collected through field observations, structured interviews, and direct evaluation of handling practices along the distribution chain, from harvesting to packing house operations. The results show that the banana supply chain follows a tiered structure involving farmers, cooperatives or packing houses, and core companies serving both domestic and export markets. Physical traceability analysis indicates that product flow is strongly influenced by coordination among supply chain actors, with the packing house acting as the main quality control point. The overall supply chain efficiency reached 79.03%, while postharvest losses accounted for approximately 20.97% of total production. Most losses occurred during the sorting stage at packing houses, mainly due to accumulated mechanical damage during handling and transportation, as well as biological deterioration related to pest and disease susceptibility and environmental exposure. These results suggest that postharvest handling represents the main critical point in maintaining banana quality within the supply chain. Improving early-stage handling practices, along with better coordination among supply chain actors, is essential to reduce losses and maintain the marketability of bananas (*Musa spp*.) in both domestic and export markets.

Keywords: Banana (*Musa spp*.); climacteric fruit; handling; postharvest loss; supply chain efficiency.

INTRODUCTION

Banana (*Musa* spp.) is one of the most widely consumed tropical fruits, valued for its affordability and rich nutritional composition, including carbohydrates, vitamins, minerals, and dietary fiber. As a climacteric fruit, bananas are generally harvested at the green stage and then undergo pre-climacteric, climacteric, and senescence phases, which are marked by a sharp increase in respiration rate and ethylene production. This physiological behavior makes bananas highly prone to rapid ripening and quality deterioration during postharvest handling, especially under suboptimal conditions of storage, transportation, handling, and packaging (Al-Dairi et al., 2023; Shinga et al., 2025). In Indonesia, bananas represent a major tropical fruit commodity with substantial production capacity. According to data from Badan Pusat Statistik (BPS), national production reached 92,603,866.58 quintals in 2024, while Lampung Province contributed 13,220,299.44 quintals in 2023 (BPS, 2024), positioning it as one of the main production centers. This high level of production not only supports domestic availability but also creates opportunities for wider distribution, including regional and export markets.

Despite this strong production base, banana supply chains remain vulnerable to postharvest losses due to the perishable nature of the fruit and the complexity of handling processes along the distribution chain. Previous studies have shown that losses commonly occur during transportation, handling, storage, and packaging, and that the application of appropriate postharvest technologies is essential to maintain nutritional, physical, and market quality (Kikulwe et al., 2018). In many cases, deterioration tends to be concentrated at specific points within the value chain, particularly where handling practices are inadequate, storage time is prolonged, or quality control is limited.

Efforts to reduce losses in fresh produce supply chains are not determined solely by technical handling practices but also by the level of coordination and information flow among stakeholders. Effective packaging practices and integrated supply chain management have been recognized as key factors in

minimizing losses and improving overall system performance (FAO, 2011). Identifying inefficiencies along the chain is therefore important for designing targeted interventions that enhance both product quality and operational efficiency (Pimentel et al., 2022). These issues are particularly relevant in banana distribution systems, where multiple actors and fragmented processes often complicate traceability and quality control.

In Lampung Province, the banana distribution system involves farmers, cooperatives or packing houses, and core companies that link production areas with domestic and export markets. However, how physical traceability, postharvest losses, and distribution efficiency interact within this system has not been fully explored. This study therefore aimed to map the supply chain, assess physical traceability, and evaluate postharvest losses of banana commodities in Lampung Province, Indonesia, in order to provide insights for improving postharvest management and maintaining banana quality throughout the distribution system.

MATERIALS AND METHODS

Study area

This study was conducted from August 2024 to May 2025 in three major banana-producing regions of Lampung Province, Indonesia, namely Central Lampung, Tanggamus, and West Lampung Regencies. These locations were selected purposively because they represent key production centers and have active involvement in agribusiness partnerships for banana production and distribution. In addition, these regions reflect the main supply chain pathways linking farmers, packing houses, and core companies serving both domestic and export markets.

The study population consisted of actors involved in the banana supply chain, with particular emphasis on cultivation and physical handling stages. From an estimated population of 1,500 banana farmers, a total of 94 respondents was determined using the Slovin formula with a 10% margin of error. Respondents were selected through random sampling to ensure equal representation. In addition to farmer respondents, supporting observations were also carried out involving collectors and 15 packing house units operating within the study area.

Data Collection

This study utilized both primary and secondary data. Primary data were obtained through field observations, structured interviews using questionnaires, and direct documentation. Data collection focused on the physical handling and biological aspects affecting banana quality along the supply chain. Field observations were conducted to examine postharvest handling practices, including harvesting, transportation, sorting, grading, washing, labeling, and packaging at packing houses. Particular attention was given to identifying sources of mechanical damage and biological deterioration that could affect fruit quality. Structured interviews were carried out to capture information on product flow, the roles of supply chain actors, and operational practices at each stage of distribution.

The key variables observed included production and harvesting conditions, physical handling processes throughout the supply chain, and biological factors influencing postharvest quality, such as exposure to pests, diseases, and environmental conditions. The implementation of cold chain systems in distribution to modern retail and export markets was also documented. Secondary data were obtained from relevant institutional sources, including the Central Bureau of Statistics (BPS), agricultural agencies, agribusiness companies, and scientific literature related to banana production and distribution systems.

Data Analysis

The collected data were analyzed using qualitative descriptive methods and quantitative calculations to assess banana supply chain structure, physical traceability, postharvest losses, and distribution efficiency in Lampung Province.

Supply chain mapping

Supply chain mapping was first conducted to describe the flow of bananas from farmers to farmer groups or sub-collectors, then to packing houses, cooperatives, core companies, and finally to domestic and export markets. This mapping was used to identify the main physical handling nodes and to trace how bananas moved through the distribution system from the production area to the final market.

Postharvest losses

Postharvest losses were quantified by measuring the proportion of bananas rejected or damaged during handling, with particular attention to the sorting stage at packing houses. The loss value (L) was calculated as follows:

$$L = \left(\frac{volume\ of\ damaged\ or\ rejected\ bananas}{total\ production}\right) \times 100\%$$

This indicator was used to estimate the extent of physical and biological deterioration occurring along the supply chain. The analysis also considered the main causes of losses, including mechanical damage during harvesting, transportation, and handling, as well as quality degradation associated with pest and disease incidence and environmental exposure.

Supply chain efficiency

Supply chain efficiency was evaluated using the distribution efficiency ratio (ER), which compared the

volume of bananas successfully sold with total production:

$$ER = \left(\frac{number\ of\ bananas\ sold}{total\ production}\right) \times 100\%$$

This measure was used to assess how effectively bananas were distributed from production centers to final markets. The integration of supply chain mapping, postharvest loss analysis, and efficiency measurement provided a comprehensive basis for interpreting the relationship between handling practices, traceability, and overall banana supply chain performance in Lampung Province.

RESULTS AND DISCUSSION

Supply Chain Structure and Physical Traceability

The banana supply chain in Lampung Province operates as a multi-actor distribution system involving farmers, farmer groups or sub-collectors, packing houses, cooperatives, core companies, and final markets. At the upstream level, farmers act as the primary producers, handling cultivation, harvesting, and the initial processing of banana bunches. After harvest, bananas are collected either by farmer groups or sub-collectors before being transported to packing houses for sorting, grading, cleaning, labeling, and packaging. This pattern reflects a tiered distribution system rather than a direct farm-to-market flow, where each stage contributes to the final physical quality of the product. Supply chain systems in agriculture are known to integrate material, information, and financial flows to generate value across the entire network (Pennekamp et al., 2024). The overall structure and flow of the banana supply chain identified in this study are illustrated in Figure 1.

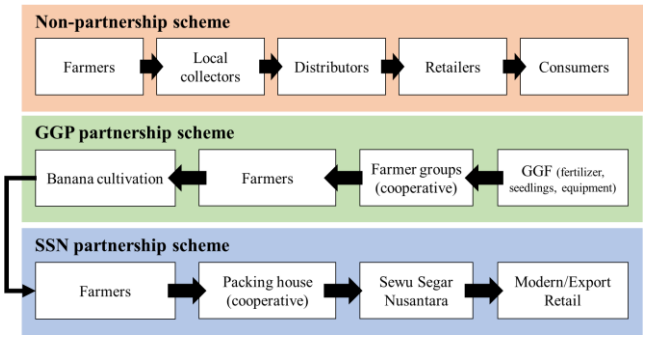

Figure 1. Supply chain scheme of banana in Lampung.

Note:

- Orange (Non-partnership scheme): A traditional distribution pathway without formal institutional involvement. Bananas are sold directly to collectors and then move through distributors and retailers before reaching consumers.
- Green (GGP partnership scheme): A farmer group-based partnership system in which cooperatives coordinate cultivation activities, while Great Giant Pineapple (GGP) manages postharvest handling and distribution.
- Blue (SSN partnership scheme): A traditional partnership model involving cooperatives and packing houses, where bananas are processed and distributed through PT Sewu Segar Nusantara (SSN) to modern retail and export markets.

Physical traceability mapping shows that the banana supply chain consists of three main stages: cultivation, postharvest handling, and distribution. Based on field observations and spatial tracking (Figure 1), the product flow follows a structured pathway in which smallholder farmers harvest banana bunches and then channel them either through local collectors or directly to packing houses under partnership schemes, such as those associated with GGP and PT Sewu Segar Nusantara.

The packing house stage emerges as the most critical control point for maintaining product quality. At this stage, fruit quality is assessed through sorting and grading based on size and physiological maturity, followed by washing and sanitation processes. For products intended for export and modern retail markets, bananas are further handled under controlled conditions, including cold storage, to reduce respiration rates and ethylene production. These processes help slow down ripening and maintain fruit quality during distribution. This indicates that packing houses function not only as logistical hubs but also as biological and technological control points that standardize both the physical and physiological quality of bananas before entering domestic and international markets, including export destinations such as Singapore and Japan.

A total of 15 packing house units operate in the study area under the coordination of cooperatives linked to PT Sewu Segar Nusantara. These facilities play a central role in quality standardization and serve as key traceability points by recording, inspecting, and conditioning the fruit prior to distribution. Proper postharvest handling at this stage is essential to maintain product quality before marketing (Kusmiati & Laudiasari, 2023). However, limited cold storage infrastructure in several facilities still contributes to additional losses (Intan et al., 2025). The spatial distribution of packing house facilities across the study regions further supports the understanding of traceability networks, as illustrated in Figure 2.

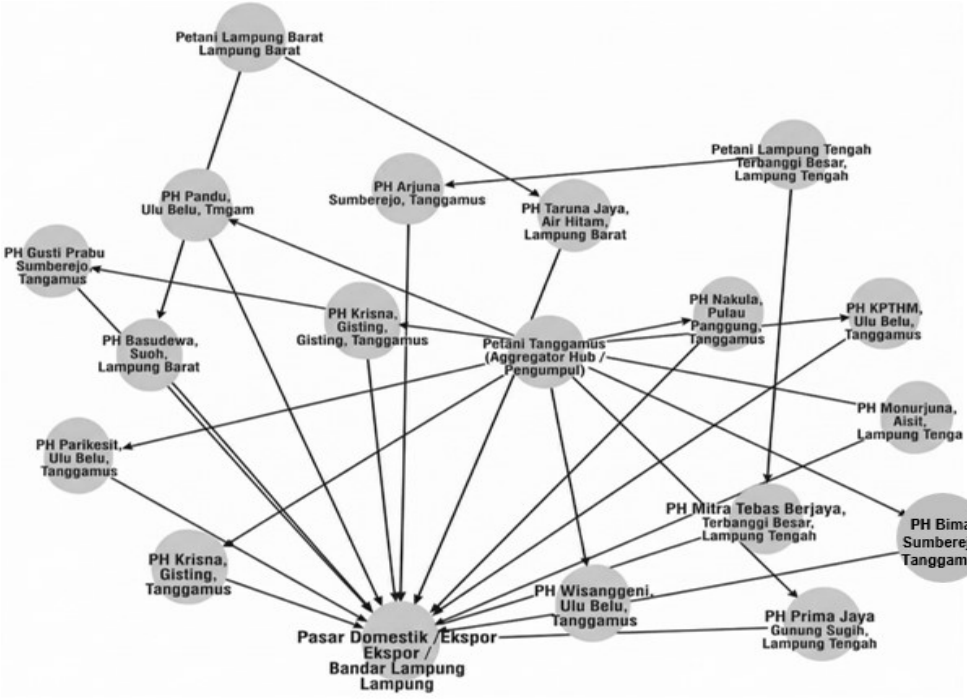

Figure 2. Banana supply chain flow diagram based on packing house (PH) location.

Three main supply chain schemes were identified. The first is a formal partnership system involving cooperatives and PT Sewu Segar Nusantara, which connects farmers to modern retail and export markets. The second involves partnerships with large agribusiness companies such as Great Giant Pineapple. The third is a non-partnership system, where farmers sell directly to local collectors through conventional distribution channels. These patterns show that the banana supply chain in Lampung combines structured and informal systems, with partnership-based schemes offering stronger traceability and more consistent quality control.

Overall, the mapping results indicate that physical traceability is closely linked to the level of coordination among supply chain actors. In partnership systems, product flow tends to be more organized and handling practices more standardized, whereas non-partnership systems show greater variability in quality control. For highly perishable commodities such as bananas, this difference is critical because physical damage and quality deterioration can accumulate quickly along the chain. In this context, traceability functions not only as a logistical tool but also as an important mechanism for maintaining product quality and marketability. The structure of the distribution system further highlights the strategic role of packing houses in determining marketing channels for both domestic and export markets (Hairurnisa et al., 2024; Andanu et al., 2021).

Postharvest Losses in the Banana Supply Chain

The evaluation of postharvest performance shows that banana (Musa spp.) distribution in Lampung Province experienced substantial physical losses, reaching approximately 20.97% of total production. From an initial volume of 2,258,000 kg, only 1,784,424 kg reached the final market, indicating a considerable reduction in marketable yield. The distribution of losses across supply chain stages is summarized in Table 1, which highlights the sorting stage at the packing house as the main contributor to total losses.

Table 1. Postharvest losses and distribution efficiency by stage.

Stage	Input (kg/year)	Loss (%)	Loss (kg/year)	Output (kg/year)
Total production	2,258,000	–	–	2,258,000
Household consumption	7,680	–	–	2,250,320
Packing House (sorting)	2,250,320	15%	337,548	1,912,772
Transport (PH → SSN)	1,912,772	5%	95,639	1,817,133
General trade (50%)	908,566	0%	0	908,566
Modern trade (30%)	545,140	5%	27,257	517,883
Export Japan (10%)	181,713	0%	0	181,713
Export Singapore (10%)	181,713	3%	5,451	176,262
Final marketed volume	–	–	–	1,784,424

The largest loss occurred during sorting and grading at the packing house, accounting for 15% (337,548 kg) of the total volume entering the facility. This rejection resulted from a combination of mechanical damage and biological deterioration. Mechanical damage, such as bruising, abrasion, and deformation, mainly originated from improper harvesting techniques and rough handling during transportation from farms to the packing house. These physical injuries weakened the peel structure and accelerated physiological degradation.

Biological factors also contributed significantly to quality loss. Symptoms such as premature ripening, enzymatic browning, and pathological decay, which often initiated by pest and disease infections in the field, became more evident during sorting. As a result, fruits that were no longer suitable for storage or distribution were removed at this stage. Additional losses occurred during transportation from the packing house to the core company (SSN), accounting for 5% (95,639 kg). These losses were largely associated with mechanical stress, vibration during transit, and suboptimal temperature conditions, all of which can accelerate respiration and ethylene production in climacteric fruits.

At the downstream level, losses varied across market channels. Distribution to modern trade resulted in a 5% loss (27,257 kg), while export to Singapore showed a 3% loss (5,451 kg), mainly due to longer handling and transportation periods. In contrast, general trade and export to Japan showed negligible losses, likely due to shorter distribution chains or stricter quality control systems. The relative contribution of each stage to total losses is illustrated in Figure 3. Overall, these findings suggest that postharvest losses are cumulative and driven by handling conditions along the chain, with the sorting stage functioning as the main point where upstream damage becomes visible and measurable.

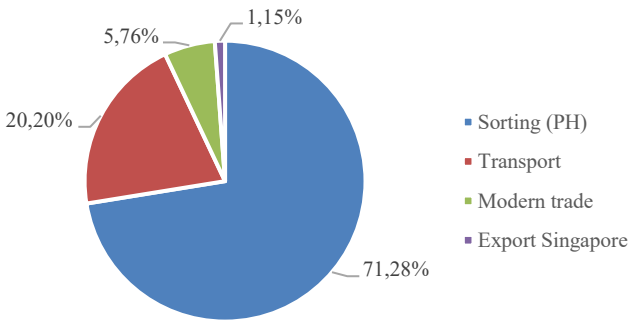

Figure 3. Contribution of postharvest losses across different stages in the banana supply chain in Lampung Province.

The total loss of nearly 21% reflects the biological vulnerability of banana (Musa spp.) as a climacteric fruit. The concentration of losses at the packing house stage, which accounts for 71.28% of total losses, indicates that maintaining fruit quality largely depends on early-stage handling and quality screening. The high rejection rate at this stage suggests that pre-harvest management and initial handling practices are still not optimal, leading to compromised fruit integrity before entering the formal supply chain. Damage to the peel increases susceptibility to microbial infection and accelerates physiological deterioration. As reported by Andanu et al. (2021), proper harvest planning and precise harvesting techniques play a key role in maintaining fruit quality and reducing structural damage along the supply chain.

Reducing these losses requires improvements in both handling practices and biological preservation strategies. Strengthening farmer skills in harvesting and handling, improving sanitation during sorting and grading, and ensuring a consistent cold chain system are important steps to slow down physiological decay and extend shelf life. These improvements are particularly relevant considering that bananas are a valuable natural product rich in complex carbohydrates, dietary fiber, and bioactive compounds such as polyphenols and anthocyanins, which contribute to antioxidant activity and nutritional value (Pakpahan et al., 2024). Maintaining these qualities through better postharvest management is essential to improve product quality and market competitiveness.

Supply Chain Efficiency

The overall supply chain efficiency was estimated at 79.03%, indicating that most of the banana production reached downstream markets. However, nearly one-fifth of total production was lost before final sale, pointing to constraints mainly related to postharvest handling and fruit quality. This efficiency level is closely linked to how losses are distributed across the supply chain. Of the total loss of 473,576 kg, the largest share occurred during sorting at packing houses, followed by transportation losses and smaller losses in modern trade and export channels. This pattern suggests that supply chain efficiency is largely determined by early-stage handling and quality screening, rather than by downstream distribution capacity.

The dominance of losses at the sorting stage indicates that efficiency is strongly influenced by the condition of the fruit upon arrival at the packing house. Mechanical damage and physiological deterioration accumulated during harvesting and initial transport reduce the proportion of fruit that meets quality standards, thereby lowering the effective output of the system. Despite these losses, the final marketed volume reached 1,784,424 kg, showing that the supply chain remains operationally effective in distributing bananas to both domestic and export markets. Even so, the reduction in marketable yield has clear implications for economic returns, supply consistency, and product standardization. Previous studies also note that supply chain efficiency is influenced not only by the proportion of products sold, but also by factors such as farmer share and marketing costs (Yusuf & Asasandi, 2025). Improving efficiency therefore requires both reducing losses through better

postharvest handling and strengthening coordination among supply chain actors.

Implications for Banana Quality and Market Competitiveness

The results highlight that banana supply chain performance in Lampung Province is shaped by the interaction between postharvest handling practices, physical traceability, and institutional coordination. Although the system effectively connects farmers with domestic and export markets, quality degradation still occurs before products reach final consumers. The concentration of losses at the packing house stage confirms its role as the main biological and technical control point, where fruit is evaluated based on both physical appearance and physiological condition.

Improving sorting accuracy, grading standards, sanitation, and handling practices at the packing house is likely to produce the greatest reduction in postharvest losses, as improper handling and mechanical damage significantly affect banana quality (Al-Dairi et al., 2023). In addition, better harvesting techniques, improved packaging systems, and more controlled transportation conditions are needed to minimize physical damage and maintain fruit integrity, since mechanical impacts during these stages accelerate deterioration and reduce marketability (Pathare et al., 2022). Strengthening cold chain infrastructure is also important to slow ripening and extend shelf life, helping preserve product quality during distribution (Jarman et al., 2023). At the same time, stronger coordination among supply chain actors can improve traceability, reduce variability in handling practices, and support more consistent product quality across markets (Bai et al., 2023).

Overall, the banana supply chain in Lampung Province can be considered functionally efficient, but still constrained by biological and handling-related factors. The combination of approximately 21% postharvest loss and 79.03% efficiency suggests that, although distribution capacity is relatively strong, overall performance is limited by postharvest management. Addressing these limitations is essential to improve product quality, reduce economic losses, and strengthen competitiveness in both domestic and export markets.

CONCLUSIONS

The banana (*Musa spp*.) supply chain in Lampung Province is structurally organized through a tiered system involving farmers, packing houses, core companies, and domestic and export markets. Physical traceability mapping confirmed that product quality is strongly influenced by handling practices at each stage, with the packing house acting as the main critical control point. Postharvest losses reached approximately 20.97% of total production, while overall supply chain efficiency was 79.03%. The majority of losses occurred during the sorting stage due to accumulated mechanical damage and the biological susceptibility of bananas as climacteric fruits. These findings indicate that supply chain performance is primarily constrained by postharvest handling rather than distribution capacity. Therefore, improving early-stage handling, optimizing sorting and grading practices, and strengthening cold chain implementation are essential to reduce losses and enhance banana quality and market competitiveness.

Authors' Contributions: Feri Safitri, Fitriani, and Sarono designed the study. Feri Safitri carried out the field work. Feri Safitri analyzed the data. Fitriani, Sarono, and Analiana Sari supervised the study. Feri Safitri wrote the manuscript. All authors read and approved the final version of the manuscript

Competing Interests: The authors declare that there are no competing interests.

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