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Risk Analysis Approach to Identifying Actions that Reduce Waste for a Lean Agricultural Supply Chain

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Abstract:

Purpose: In this study, we examine the food loss food waste (FLFW) risks in agricultural supply chain through combination the risk analysis approach and lean principles.

Design/methodology/approach: The methodology of this study includes the actor analysis, risk analysis approach, and lean principles. The actor analysis is conducted to identify the actor's needs, problems, and characters. The risk analysis approach was combined with lean supply chain principles to identify risk points for FLFW in the agricultural supply chain for cayenne pepper in Indonesia. A risk-lean relationship matrix was developed to identify waste reduction efforts.

Findings: In this study, the lean-risk matrix was created to discover the similarities and differences in waste reduction efforts in agricultural products compared with traditional manufacturing products, which can also apply to agricultural products in this case study.

Research limitations/implications: This study focuses on combining the risk analysis and lean principles to determine the FLFW risk on the agricultural supply chain and find possible solutions to mitigate those risks. The case study for this research is the cayenne pepper supply chain.

Originality/value: Lean principles in the FLFW problem are rarely found in studies. Lean principles are an approach that can be used to obtain solutions to reduce waste.

Keywords: lean principles, food loss, food waste, risk analysis, agricultural supply chain

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1. Introduction

The world has recognized the need to protect the environment and enhance social quality in the pursuit of economic growth. The concept of Sustainable Development Goals (SDGs) offers a way to address problems with balancing economic growth, environmental protection, and social inclusion. In 2015, 193 member states of the United Nations committed to 17 SDGs (FAO, 2018), several of which are related to how resources are consumed.

Food is not harvested, produced, and consumed efficiently and effectively, which creates food loss and food waste (FLFW). Therefore, one SDG is to reduce global FLFW (FAO, 2018). Reducing FLFW is directly linked to sustainable development because of its effect on societies, economies, and the environment (Moult, Allan, Hewitt & Berners-Lee, 2018). At the microlevel, FLFW generates economically unacceptable waste (FAO, 2018) because it increases production costs beyond the income received (Mohammadi, Jämsä-Jounela & Harjunkoski, 2019). FLFW may also have an environmental impact through carbon emissions (Galford, Peña, Sullivan, Nash, Gurwick, Pirolli et al., 2019). At the macrolevel, FLFW reduces the food availability for many people. The Food and Agriculture Organization (FAO) estimates that one-third of global food production is lost or wasted. Hence, FLFW and its impact on sustainability must be understood.

FLFW is a problem for both developed and developing countries. Developing countries are the most significant contributors to FLFW in the world (TRTWorld, 2018). The FAO (2018, 2019) has reported high levels of FLFW in the agricultural production process of developing countries. Parfitt, Barthel and Macnaughton (2010) noted that FLFW by developing countries mainly occurs during agricultural production and in the agricultural supply chain. Agricultural products are bulky and perishable, so they require more complex handling and transportation to minimize FLFW. They have a strict time window to be processed, shipped, marketed, and stored. Generally, they become more vulnerable to damage over time (Gokarn & Kuthambalayan, 2017). Agricultural supply chains are complex systems that face the challenge of maintaining the freshness of agricultural products during staging, handling, packaging, and storage (Gokarn & Kuthambalayan, 2017; Parfitt et al., 2010). They usually require a temperature-controlled process postharvest to maintain the quality of the agricultural products (Parfitt et al., 2010). Agricultural supply chains are owned and managed by different actors with different needs and priorities. All of these differences introduce risks that allow FLFW to occur.

Thus, one approach to reducing FLFW is to use a risk analysis framework to identify risk points in an agricultural supply chain. The risk analysis must consider all relevant stakeholders because the supply chain involves interdependent interactions between multiple actors (Heckmann, Comes & Nickel, 2015). Risk analysis can be used to identify what has gone wrong based on the past and what can go wrong in the future. In this study, risk analysis was combined with lean supply chain (LSC) principles to identify and map potential FLFW risk points along the agricultural supply chain as well as find possible solutions. The proposed approach was applied to the agricultural supply chain of a developing country as a case study. The identified risk points were used to develop a risk-lean relationship matrix for mapping possible LSC-based measures to minimize these risks.

2. Literature Review

2.1. FLFW as a Risk in the Agricultural Supply Chain

Agricultural products are perishable, vulnerable to environmental damage, and can have a long lead time from harvest to being sold (Yan, Chen, Cai & Guan, 2020). They need special treatment to maintain their freshness as they have a very high chance of becoming waste along the supply chain. FLFW was initially assumed to mainly occur in the agricultural production process of developing countries (Parfitt et al., 2010). However, the FAO (2018) has reported that FLFW also occurs in the processing and packaging stages. Therefore, attention must be given to the supply chain as well as production. If FLFW is analyzed as an end-to-end system of interconnected agricultural supply chains, the complete economic and environmental impact of waste can be assessed for both upstream and downstream supply chains. Delgado, Schuster and Torero (2020) noted that most of the previous literature on FLFW did not consider the different characteristics and complexity of upstream and downstream supply chains. Upstream supply chains have a risk of overproduction due to demand uncertainty, especially if there is no coordination between producers and the market in terms of taking and fulfilling orders (Contini, Marotta & Torquati, 2020; Hannachi, Coleno & Assens, 2020; Qiu, Hu & Xu, 2020; Yan et al., 2020; Yan, Chen, Yuan & Zhou, 2019). Overproduction leads to excess inventory, increased FLFW, and increased operating expenses (Ma, Wang, Islam & Liu, 2019). Overproduction also increases pollution and emission levels owing to increased use of energy, machinery, and technology (Syahruddin & Kalchschmidt, 2011). Limited technology and inadequate knowledge of good handling practices can also lead to difficulty with maintaining the quality of fresh food (Hannachi et al., 2020; Mohammadi, Ghazanfari, Pishvaee & Teimoury, 2019; Qiu et al., 2020).

To avoid FLFW, transportation (Wang, Cheng, Huang & Cheng, 2020) and storage infrastructure (Bai, Zhao & Li, 2019) such as cold chain facilities are required to ensure that agricultural products arrive at markets on time and fresh (Hannachi et al., 2020; Nematollahi & Tajbakhsh, 2020; Yan et al., 2020). This creates challenges for tracking, packaging, and inventory control (Yan et al., 2019). Addressing all of these issues incurs additional costs and energy consumption that affect the environment.

For a downstream supply chain, FLFW occurs when a product expires and must be discarded, which results in lost sales (Moult et al., 2018). Retailers and food service providers try to keep food fresh by using storage technology, which increases operating costs. Overall, FLFW reduces the optimal performance of the supply chain as a whole (Mohammadi, Jämsä-Jounela et al., 2019). Thus, FLFW should be considered as a risk in agricultural supply chains (Nyamah, Jiang, Feng & Enchill, 2017). The risk analysis approach can be used to comprehensively consider possible losses in the past, present, and future, especially for uncharted agricultural products. Risk analysis can be used to identify not just what has happened but also what could happen. Heckmann et al. (2015) wrote that risk analysis must involve all relevant stakeholders or actors because the supply chain comprises interdependent interactions. Each part of a supply chain is managed and influenced by different actors, which must be identified to understand their perspectives and interests through multiactor analysis (Sun, Zhang, Wang, Li & Sheng, 2015). Multiactor analysis can help identify the risk points of a supply chain based on the actors (Almeida, 2019), particularly by identifying the perception gap between ideal and expected conditions (Bergqvist, Macharis, Meers & Woxenius, 2015).

The failure mode effect and analysis (FMEA) method can be used to find potential risks, their causes, and potential actions to realize the optimal solution. FMEA is used to weigh and prioritize risks to help managers find the right strategy (Rezaee, Yousefi, Valipour & Dehdar, 2018). FMEA identifies system defects and their causes, their effect on the system performance, and solutions to reduce the chances of occurrence and consequences of failure, which are used to calculate the risk priority number (RPN) (Dong & Cooper, 2016). Previous studies have used FMEA to evaluate supply chains for risk. Rohmah, Dania and Dewi (2015) used FMEA to evaluate the risk of the organic rice supply chain in East Java, Indonesia. They found that the highest risks to the supply chain were commodity product return, damage or loss of quality, and contamination during processing (Rohmah et al., 2015). FMEA has also been applied to assessing the risk to maritime supply chains (Wan, Yan, Zhang, Qu & Yang, 2019). Wu and Hsiao (2020) applied FMEA to assessing risks to the quality and safety of the cold food supply chain. They demonstrated that FMEA could be used as a preventative tool for identifying risks and finding mitigation strategies.

2.2. Principles of an LSC

To reduce FLFW, one of the most attractive approaches is to apply LSC principles, which are commonly used to fight waste in the manufacturing industry (Manzouri, Ab Rahman, Saibani & Zain, 2013). An LSC is a group of organizations that are directly linked by the flow of products, services, finance, and information from upstream to downstream that work collaboratively to reduce costs and waste while meeting individual customer needs (Vitasek, Manrodt & Abbott, 2005). An LSC is essential for reducing waste and optimizing value-added activities. Implementing LSC principles reduces inventory, excess capacity, transportation, and production time while increasing the integration and frequency of information flow (Carvalho, Duarte & Machado, 2011, as cited in Martínez-Jurado & Moyano-Fuentes, 2014)

An LSC is a perfect solution to FLFW, which occurs because of overproduction, inadequate storage facilities, poor material handling, lack of infrastructure, and improper processes along the supply chain (Munesue, Masui & Fushima, 2015). FLFW can also be caused by imperfect processes along the supply chain and a market demand for high quality, which causes large amounts of products to be rejected owing to defects (Dora & Gellynck, 2015). An LSC focuses on optimization by simplifying processes, reducing waste, and reducing non-value-added activities along the supply chain (Afonso & Rosário-Cabrita, 2015). Previous research has indirectly discussed applying LSC principles to FLFW. Afonso and Rosário-Cabrita (2015) found that an LSC can be implemented for small- and medium-sized enterprises (SMEs) that operate in the food industry. Zarei, Fakhrzad and Paghaleh (2011) applied the house of quality and quality function deployment methods to reduce waste in the food supply chain according to LSC principles. Dora and Gellynck (2015) provided an LSC-based framework for food processing SMEs to reduce waste such as excess inventory, lead time, and defects that affect food safety, sustainability, quality, and cost. They suggested exploring the applicability of LSC principles to the agricultural industry. Reis, Kipper, Velásquez, Hofmann, Frozza, Ocampo et al. (2018) explored implementing LSC principles in the coffee sector to reduce losses. Value stream mapping has been applied to evaluating the agrifood supply chain for waste during the harvesting, transportation, packaging, and handling processes (Folinas, Aidonis, Triantafillou & Malindretos, 2013). However, more research is needed on applying LSC principles to agricultural supply chains.

3. Research Methodology

3.1. Case Study: Cayenne Pepper in Indonesia

In Indonesia, one agricultural product that is very susceptible to FLFW is cayenne pepper. Indonesia is the fourth largest producer of cayenne pepper in the world and produced 1,374,217 tons in 2019 (BPS-Statistics Indonesia, 2020). However, Figure 1 shows that the amount of consumption is far less than the amount of production, which indicates the potential for large amounts of FLFW. Cayenne pepper is used for cooking in Indonesia and other Southeast Asian countries, either fresh or processed. The supply of cayenne pepper depends on the production amount, which can be predicted from the total harvest area and land productivity. However, the productivity is very susceptible to temperature changes, which creates a disparity between supply and demand and leads to relatively large price fluctuations. Thus, cayenne pepper was selected as a case study because of its multi actor supply chain, which has not previously been considered for risk analysis.

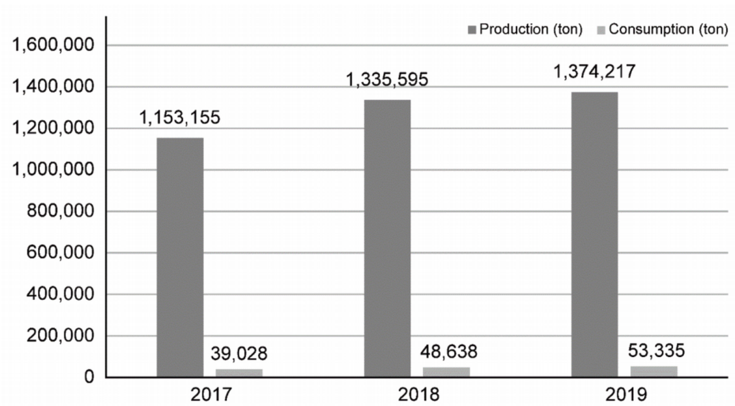

Figure 1. Production and consumption of cayenne pepper in Indonesia for 2017-2019

3.2. Methodology

In this study, risk analysis and LSC principles were combined, as shown in Figure 2. The agricultural supply chain for the case study was mapped, and the actors for various processes were analyzed. A man, money, machine, material and methods, information, and energy (5M + IE) analysis was performed to characterize the agricultural supply chain. Risks were identified for each process of the chain, and actors were analyzed for their efforts to manage flows to reduce potential risks and their effects. Actors were analyzed in three dimensions: logistical, technical, and financial ability. Logistical ability includes transportation and technology to meet demand (Jaffee, Siegel & Andrews, 2010). Technical ability includes business development. Financial ability includes capital and government subsidies that help actors develop their business. These three dimensions were used to guide interviews with actors.

FMEA was then used to map the risks of different processes and identify mitigation strategies on the basis of LSC principles. The goal was to identify waste as a non-value-added product to make it easier to eliminate and improve production (Folinas, Aidonis, Voulgarakis & Triantafylou, 2013). Data selection used purposive technique as shown at Appendix A. Data were collected through depth interviews, and the investigators also requested the companies for secondary data. Interviewees were determined starting from the downstream to the upstream of the supply chain, i.e., we determined the retailers as the first step to determine the supply chain networks. Subsequently, we could identify two collectors who work with retailers. From the interviews with collectors, we could identify farmer groups supplying them with cayenne peppers. There are five farmer groups represented by their leaders for the depth interview.

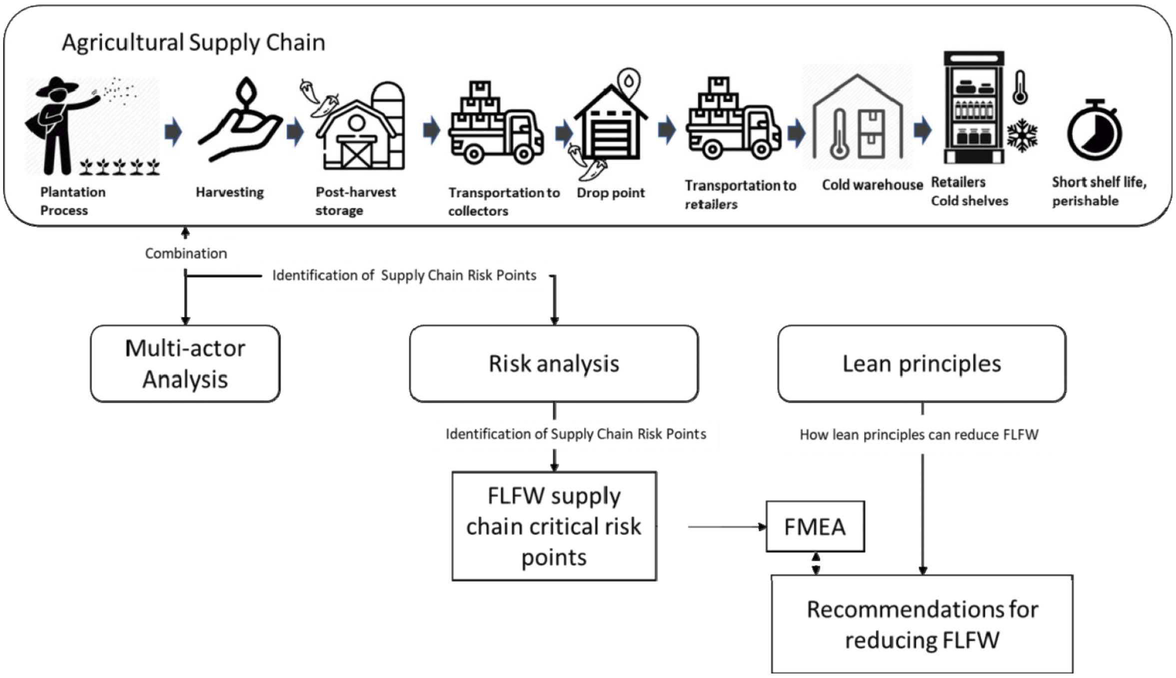

Figure 2. Concept of risk analysis for an agricultural supply chain

As shown in Figure 3, one of the preliminary steps herein is the literature review. The preparation of the literature review was conducted by searching for references via keyword search "FOOD LOSS AND FOOD WASTE," "AGRICULTURAL SUPPLY CHAIN," "RISK ON AGRICULTURAL SUPPLY CHAIN," AND "LEAN SUPPLY CHAIN." These references were used as the base to identify the main issue of this study and to develop the proposed research model. References are used from various resources, such as Elsevier (www.sciencedirect.com), Scopus (www.scopus.com), and Springer (www.springerlink.com). We found that there is limited literature regarding lean principles when discussing the issue of FLFW. These studies only discuss lean concepts in general but not in detail. Therefore, it is noteworthy to discuss lean concepts in FLFW in this study.

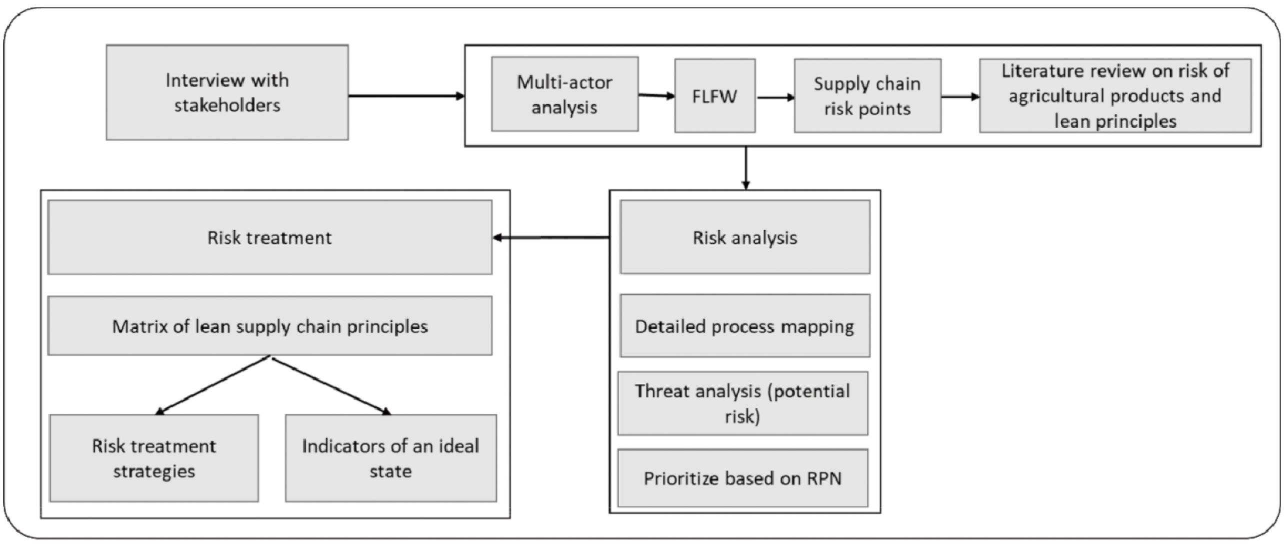

Figure 3. Research methodology

4. Results and Discussion

4.1. Supply Chain Characteristics Map

The supply chain was mapped to describe and identify the current flow of products and information for every process at all stages, as given in Table 1. Seven processes were identified in the supply chain from farmer to retailer. The 5M + IE analysis was performed to identify the variables and processes that influenced the supply chain. Information between farmers and retailers flowed through phone and messaging services. Stakeholders did not solve problems jointly. The biggest problem was maintaining the freshness of products. Few cold facilities were available, especially for farmers. Table 1 indicates three actors with essential roles in managing the supply chain: farmers, collectors, and retailers.

Process	Description	5M + IE Analysis
Planting	Select seeds, place them in the soil, and tend them until harvest	Conventional planting method Pesticides from the government Low- and medium-quality seeds Optimize land use Planting in good weather (sunny days) Farmers
Harvesting	Collect agricultural products from the cultivated land	Collect products by hand Use a wheelbarrow to carry the products to the drop point Products are harvested according to the maturity level requested by the buyer Products are kept in gunnysacks Farmers
Storage	Manage products in stock to ensure their availability	Use gunnysacks to keep the products No chiller used to maintain the freshness of products No warehouse Farmers and buyers communicate by phone Farmers
Distribution to collectors	Deliver products from suppliers to distributors or collectors with limited transportation facilities	Pickup truck used to deliver products to buyers Products are carried in gunnysacks Delivery time to the buyer is 2.5-3 h Farmers
Drop point	Transit point before products are distributed to retailers Sort good and defective products here	No cold facility Products are stored in a Styrofoam box Inventory time is 1-4 days Products are cleaned, sorted, and stored before distribution to retailers Collectors
Distribution to retailers	Distribute the finished product to customers	Delivery of products to retailers with limited transportation facilities No cold transportation Products are carried in plastic bags Delivery time to the retailer is 2-3 h Collectors
Storage and display	Sell a product once it arrives at the retailer Products are packaged and displayed at the counter	When the products arrive, staff sort and weigh them Products are kept in cold storage Products are ordered from suppliers by phone 30 kg per order Products are stored in a warehouse for a day before the display Products that start to dry are packaged in Styrofoam and plastic Warehouse layout an essential consideration for maintaining the freshness of the product

Table 1. Map of the supply chain characteristics

4.2. Actor Analysis

An actor analysis was performed to determine their needs, problems, and strengths. Table 2 presents the results of the actor analysis. The stakeholders in the supply chain (i.e., farmers, collectors, and retailers) each had different interests and problems. Some actors possessed similar interests, problems, and objectives. Farmers and collectors had more similarities than retailers because their businesses were smaller in size than the retailers. All actors possessed a common interest in increasing profits. They observed potential risks because of limited facilities and long sale periods. The actors had no significant conflicts of interest, which made it easier to generate a better coordination mechanism.

Actors	Farmers	Collectors	Retailers
Supply chain area	Planting Harvesting Storage Distribution to collectors	Drop point Distribution to retailers	Storage and display
Problem perception	Low crop quality Low demand Loss of humidity Few facilities	Low supply Loss of quality High purchase price Few facilities	Many damaged products Reduced quality Excess inventory
Objectives	High selling price Fulfill customer demand High product quality	High selling price Fulfill customer demand Sell all remaining inventory	Fulfill customer demand Decrease excess inventory level Reduce the number of damaged products
Interest	Profit	Profit	Profit
Cause of problem	Inadequate infrastructure Supply and demand are unbalanced Long-term storage	Inadequate infrastructure Supply and demand are unbalanced Long-term storage Many damaged products Long shipping and selling times	Long sale period Expired date Supply and demand are unbalanced
Resource	Own the land Producer	Strong network with farmers, retailers, manufacturers, and government Lobbying power	Capital Lobbying power
Position	Expect government/private assistance for infrastructure improvement	Lobby farmers to sell at a low price, lobby manufacturers and retailers to buy at high prices, especially low-quality products Build good relationships and communication with supply chain partners	Request low prices for products with reduced quality Balance supply and demand through communication and demand forecasting

Table 2. Actor analysis

4.3. Supply Chain Risk Points

Supply chain risk points refer to parts of the supply chain where losses could occur as derived from the actor analysis. A literature review and in-depth interviews were used to identify risk points, as listed in Table 3. Most risk points were identified because of inadequate facilities and inappropriate processes. Many risk points were found in the transportation process, drop point, storage, and display stages. Risks in the transportation process were attributed to a lack of cold facilities to maintain the temperature of the product during trips. Additionally, Indonesia's hot tropical climate increases the risk that products ripen faster and spoil during trips. Products are stored in plastic bags that are easily damaged, so they can spill out, and hot plastic can easily damage the products. Another risk is vehicular problems or traffic jams. This risk increases uncertainty and is difficult to predict. The drop point stage has four risk points caused by external and internal factors. Many products received do not meet quality standards, and low demand results in excess inventory. Additionally, actors often do not have enough cold storage to store the product. For retailers, risk points during the storage and display processes include low demand, unclean storage, cold storage breakdown, and damaged packaging. According to The above analysis indicated that planting and harvesting have the fewest risk points among the processes within the supply chain. However, this does not mean that planting and harvesting have the lowest potential risk.

	Description
Planting	Low-quality seeds Plant in improper land
Harvesting	Low-quality product Overripe products
Storage	Humidity loss caused by long-term storage Unclean process (Munesue et al., 2015) Excess inventory (Munesue et al., 2015)
Inbound transport	Vehicle breakdown Product spillage Product loss due to temperature
Drop point	Defective products Unclean process Excess inventory (Munesue et al., 2015) Breakdown of cold storage (Munesue et al., 2015)
Outbound transport	Vehicle breakdown Product spillage Product loss due to temperature
Storage and display	Low demand Unclean storage Breakdown of cold storage Damaged packaging (Munesue et al., 2015)

Table 3. Supply chain risk points

4.4. Critical Risk Point Identification Using the FMEA Method

After the risk points were identified, the FMEA method was applied to identify critical risk points:

$$\text{Risk Priority Number (RPN)} = \text{Severity (S)} \times \text{Occurance (O)} \times \text{Detection (D)} \quad (1)$$

where S is the potential effect of failure, O is the probability of failure to occur, and D is the current process control for failure. A higher RPN indicated a more critical risk point. These risks were assessed by the farmers, owner of the collector company, and fresh produce supervisor of the retailers. Table 4 presents the results, which can be summarized as follows:

- For farmers, the highest RPNs were for R8 (incorrect movement handling) and R3 (waterlogged land). Parfitt et al. (2010) stated that farmers in developing countries have high FLFW because of a lack of facilities and knowledge. Raut, Gardas, Narwane and Narkhede (2019) also noted that a lack of cold facilities for storage and loading/unloading could affect the freshness and form of perishable products. The lowest RPN was for R10 (excess inventory), which is caused by overharvesting with low demand. This occurs when farmers try to optimize land use without predicting demand. A long storage time causes the product to eventually incur damage. Hence, at high inventory levels, farmers sell products at low prices. Even then, product buildup still occurs.
- For collectors, the highest RPN was for R19 (inappropriate storage). Collectors use gunnysacks, which are not suitable for storing perishable products. The storage material influences the ripeness level of cayenne peppers (Melone, Altomare, Cigada & De Nardo, 2012). The best storage material for cayenne peppers is transparent polyethylene packaging (Rochayat & Munika, 2015). Using gunnysacks causes the product to pile up and temperature to increase; this makes the product bruise more easily. The second highest RPN

was for R14 (below standards). Collectors and retailers have a contract regarding the quality standard of products. Retailers require all kinds of perishable products that they order to meet high standards. If the products do not meet these standards, they are rejected.

- For retailers, the highest RPN was for R25 (unclean storage). Unclean storage can cause the product to be contaminated and is caused by a lack of care and discipline on the part of humans. To combat this, retailers train staff to handle fresh produce when they are hired. The second highest RPN was for R23 (quality standards not met), which takes place during the sorting process. Products that do not meet quality standards are rejected and returned to the collector. However, if the products were damaged after the sorting process, the retailer destroys the product. The lowest RPN was for R28 (damaged packaging). This risk can make the product easy to bruise and spoil. However, the risk is low because retailers already have packaging standards.

Activities	Potential failure mode (damage)	Potential effect of failure (risk)	S	Potential cause of failure	O	Current process control	D	RPN
Seedling selection	Decline due to age and susceptibility to disease (R1)	Vulnerable to pests and diseases	8	Low-quality seeds	2	Visual check	3	48
Breeding	Low-quality seedlings (R2)	Spoilage	8	Bad seedlings	2	Visual check	3	48
Cultivation	Waterlogged land (R3)	Crop failure	7	Bad weather	3	None	7	147
Cultivation	Planting in the improper area (R4)	Vulnerable to pests and diseases	9	Lack of knowledge by the farmer	1	Optimized land use	6	54
Harvesting	Humidity loss caused by long-term storage (R5)	Product spoilage	7	Long time between storage and harvesting	1	Visual check	8	56
	Mature harvesting (R6)	Easy bruising	7	Misinformation from collectors	2	None	8	112
	Inappropriate storage (R7)	Easy bruising	3	Lack of knowledge and facilities	5	None	8	120
	Incorrect movement handling (R8)	Product spillage	4	Lack of knowledge and facilities	5	None	8	160
Storage	Unclean process (R9)	Impurity contamination	3	Lack of technology and knowledge by farmers	4	Use plastic bags to hold products	8	96
	Excess inventory (R10)	Easy bruising	2	Overharvesting	8	Visual check	3	39
				Low demand	5			
Transportation	Vehicle breakdown (R11)	Distribution delay	5	Bad maintenance	1	None	7	35
	Damaged plastic bags (R12)	Product spillage	6	Low-quality storage	2	None	2	24
	Product loss due to temperature at delivery (R13)	Potential bruising and spoilage	7	Temperature increase	3	None	7	147
Sorting and selection	Below standards (R14)	High level of FLFW	5	Low-quality products	5	Visual check	4	100

Activities	Potential failure mode (damage)	Potential effect of failure (risk)	S	Potential cause of failure	O	Current process control	D	RPN
Storage	Inappropriate product cleaning (R15)	Easy bruising	3	Lack of staff	5	None	5	75
	Unclean storage (R16)	Easy bruising	5	Lack of staff	4	Visual check	3	60
	Excess inventory (R17)	Easy bruising and spoilage	4	Low demand	3	Visual check	2	24
	Long storage time (R18)	Easy bruising and spoilage	3	Low demand	2	Visual check	2	12
	Inappropriate storage (R19)	Easy bruising and spoilage	6	Lack of staff	5	None	4	120
Transportation	Vehicle breakdown (R20)	Distribution delay	3	Bad maintenance	2	Maintenance schedule	2	12
	Damaged plastic bag (R21)	Product spillage	3	Bad quality of storage	3	None	3	27
	Product loss due to temperature at delivery (R22)	Potential bruising and spoilage	3	Temperature increase	4	None	5	60
Sales	Products below standards at the sorting process (R23)	Many defect products	4	Bad handling during distribution from farmers to retailers	3	None	10	120
	Low demand (R24)	Excess inventory	5	Bad forecasting	3	Monitoring and rescheduling orders	3	45
		Product wastage	5					
	Unclean storage (R25)	Easy bruising	8	Lack of staff	5	Control and monitoring	3	120
	Inappropriate storage (R26)	Easy bruising	4	Lack of staff	2	Control and monitoring	2	16
	Breakdown of cold storage (R27)	Easy bruising and spoilage	10	Bad maintenance	2	Scheduling	2	40
		Temperature increase	10					
	Damaged packaging (R28)	Easy bruising and spoilage	3	Bad packaging quality	2	Standardized packaging quality and material	2	12

Table 4. Risk table

4.5. Identifying Lean Practices for Risk Management (Risk-Lean Relationship Matrix)

The literature review identified some lean practices that have been used to improve performance and reduce waste in supply chains (Arif-Uz-Zaman & Ahsan, 2014). Eight lean practices can be implemented: a collaborative supply chain, functional packaging design, standardized work procedures to assure quality control, lean training, cold facilities, a close relationship with suppliers, inventory control, and quality control activities throughout the supply chain. Another factor is government support; this is not considered a lean practice, but it can significantly reduce FLFW.

- Collaborative supply chain: Das (2018) stated that collaboration between stakeholders plays a significant role in reducing waste in an LSC. Partnerships between suppliers and service providers can reduce inventory and ensure the quality of the supply.
- Quality packaging: Food packaging requires special knowledge so that products can last a long time. Medium- and large-scale food wholesalers possess more knowledge and resources than microscale and small-scale wholesalers (Bourlakis, Maglaras, Aktas, Gallear & Fotopoulos, 2014). Good packaging quality maintains product freshness.
- Standardized work procedures: Das (2018) stated that work procedures should be standardized to ensure process and product quality. This can eliminate waste in the process and outcome. Standardization can also help control the time and performance of a process (Arif-Uz-Zaman & Ahsan, 2014).
- Lean training: The implementation of lean concepts necessitates training, especially in terms of product distribution, product storage, and maintaining a good relationship with supply chain partners (Das, 2018). All actors can be educated by lean training to help them improve their performance. Lean training ensures that capable staff is available and helps realize work standardization.
- Cold storage: Cold storage keeps products fresh and maximizes their shelf life to minimize waste. Cold storage also helps with managing inventory and ordering schedules. Cold storage is very much needed for agricultural supply chains but also increases energy consumption and operating costs (Bourlakis et al., 2014). Hence, cold storage is most suitable for use by large-scale companies.
- Inventory control: Inventory control involves balancing the supply and demand of a product. Imbalances between supply and demand are caused by uncertainty, and this can risk shortages or excess inventory. Excess inventory causes a buildup of products that can be easily damaged over time. Arif-Uz-Zaman and Ahsan (2014) used inventory control as an LSC indicator. Inventory control ensures efficient production.
- Quality control: Jasti and Kodali (2015) set quality improvement as a pillar of the LSC approach. A food product must go through stringent quality control along its supply chain because it is very vulnerable to the risk of FLFW. Quality control requires collaboration between stakeholders in the supply chain (Dania, Xing & Amer, 2018). The most important aspect of quality control is ensuring that stakeholders are aware that sustainability is their responsibility.
- Government support: Government support is necessary for increasing food security and realizing SDGs. For farmers, the most crucial support they can receive from the government is good-quality seeds, high-quality fertilizers, and facilities supporting cold storage. Government support influences the ability of farmers to improve their quality and innovation (Hartwich & Jansen, 2007). Government subsidies have a positive impact on production, sustainability, and food safety (Zhang, Ma & Liu, 2020).

Table 5 shows a risk-lean relationship matrix map that was created on the basis of this literature review to visualize the interconnectivity between risk points and lean practices. This map can be used to identify which lean practices are the most and least suitable for each part of the agricultural supply chain. Overall, quality control was found to be the most suitable lean practice for this case study. It can be used for all processes and in almost every stage. Quality control is important, especially when the product is perishable and easily bruised. Thus, all actors must monitor and control the process and product condition routinely. The second lean practice that is widely applicable is standardized work procedures to make it easier for workers to do their jobs. Work standardization should maintain consistency in work and product quality. By contrast, the least suitable lean practices were using high-quality packaging and inventory control because they can only mitigate certain risks. Further risk analysis was needed to determine the stages of the supply chain with the highest potential risk.

	Collaboration lean supply chain	Quality packaging	Standardized work procedures to assure quality achievement	Lean Training	Cold storage	Inventory Control	Quality control activities	Government support
R1								7, 8
R2							5	7, 8, 9
R3					2			7, 8, 9
R4			4					7, 8, 9
R5					2, 5		5	
R6	1				2, 5			
R7			4		1			
R8			1				5	
R9			4	1			5	
R10	1, 6, 9					3, 6		
R11			1, 4	1	2		5	
R12		2						
R13					2		5	
R14			1, 4	1	2		5	
R15			1, 4	1			5	
R16			1	1			5	
R17			1, 4	1			5	
R18	1, 6					3, 6		
R19			4		11			
R20			1, 4	1	2		5	
R21		2						
R22					2			
R23			1, 4	1	2		5	
R24	1, 6, 9					3, 6		
R25			1	1			5	
R26			4	1	11			
R27			1				5	
R28		2			2			

Legend: 1: Das (2018); 2: Bourlakis et al. (2014); 3: Arif-Uz-Zaman & Ahsan (2014); 4: Jeff & Dave (2020); 5: Jasti & Kodali (2015); 6: Iyer, Srivastava & Srinivasan (2019); 7: Hartwich & Jansen (2007); 8: Zhang et al. (2020); 9: Tutuhatunewa, Surachman, Santoso & Santoso (2019); 10: Zhang, Li, Yu & Yao (2018); 11: Wiryawan & Djatna (2020).

Table 5. Risk-lean relationship matrix

5. Conclusions

In this study, the FMEA and LSC principles were integrated to realize a risk analysis approach for an agricultural supply chain. The risk analysis approach was applied to the case study to identify the highest risk of FLFW for each stage and actor involved in the supply chain. For farmers, the highest potential risk was incorrect movement handling, which can be attributed to a lack of facilities and/or knowledge. This risk can be addressed through lean practices such as work standardization, training, and quality control. For collectors, the highest risk was an increase in the product temperature during delivery because of a lack of cold facilities for distribution. For retailers, the highest risk was unclean storage due to human errors, which can be attributed to a lack of work standardization and/or knowledge. A risk-lean relationship matrix was generated to identify solutions for reducing these risks. Several processes had common risks, but the solutions differed depending on the process and actor, which were primarily attributed to differences in the characteristics and scale of the actors' businesses. Combining risk analysis with LSC principles resulted in a more detailed and in-depth analysis of possible risks and solutions to reducing FLFW. Future research can involve developing a quantitative model to detail and test the connectivity between matrix variables.

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Declaration of Conflicting Interests

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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Appendix A

Consolidated Criteria for Reporting Qualitative Research

Personal characteristic	
Interviewer/ Facilitator	Akhmad Hidayatno, Nurul Chairany
Credentials	Prof./ M.T
Occupation	Professor/ Research Association
Gender	Male/ Female
Experience and Training	Academic researcher
Relationship with Participants	
Relationship established	Had no prior relationship with interviewees
Participant knowledge of the interviewers	Participants as experts and actors who have knowledge related to research issues
Interviewer Characteristic	No characteristics were reported
Participant Selection	
Sampling	Purposive
Method of Approach	Depth interview, face to face
Sample size	5 farmer groups, 2 collectors, and 6 retailers
Non-Participation	There is no participation withdrawal
Setting	
Setting of Data Collection	6 participants of retailer were interviewed in meeting room of their office
	5 farmer groups were interviewed in a private co-working space. 2 collectors were interviewed in their warehouses
Data Collection	
Interview guide	The authors wrote the questions and the risk assessment table on papers that were given to the participants
Repeat Interviews	No
Audio/Visual recording	Audio recording
Field Notes	No
Duration	Depth interview with farmers took ~120 minutes, 24 minutes/farmer in estimation. Depth interview with retailers took 45 minutes/retailer. Depth Interview with collectors took 45 minutes/collector

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