

# Risk Evaluation of Food Loss in the Curly Red Chili Supply Chain Using the Risk Impact Matrix and ALARP Analysis

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## ABSTRACT

Risk management serves a crucial role in evaluating agricultural supply chains, particularly for perishable commodities such as curly red chili peppers (*Capsicum annuum* L.), which are highly susceptible to food loss due to biological characteristics, climate dependency, price volatility, and fluctuating distribution and demand. These conditions increase the risk of food loss throughout the supply chain, from upstream to downstream. However, reducing losses remains challenging without systematic risk identification and visualization. This research aims to visualize and determine risk tolerability at each stage of the curly red chili supply chain using the integration of the Risk Impact Matrix and ALARP (As Low As Reasonably Practicable). The study was conducted in Pasar Legi as a distribution area and Cepogo as a chili-producing location. A descriptive research approach was applied, with data collected through direct interviews and observations including farmers, collectors, wholesalers, and retailers. Risk assessment was analyzed by measuring the probability, consequence, and tolerability of each identified risk, followed by visualization using the Risk Impact Matrix and ALARP framework to determine risk tolerance and severity levels. The results indicate that seasonal and weather changes, pest and disease infestations, chili weight

loss, improper handling practices, and supply fluctuations represent the most critical risks, categorized as extreme and positioned in the red zone of the matrix. Several other risks were classified as moderate to high (ALARP), indicating the need for mitigation measures to prevent escalation. This research provides a practical risk evaluation framework to support food loss reduction and improve the efficiency and sustainability of the curly red chili supply chain.

**Keywords:** *Capsicum annuum*, chili supply chain, food loss, risk evaluation, risk impact matrix.

## INTRODUCTION

Curly red chili pepper (*Capsicum annuum* L.) represents one of the most strategically significant commodities within both the agricultural and economic sectors at a global scale, as evidenced by its extensive cultivation area, substantial production volume, high commercial value, and considerable consumption rates [1]. Curly red chili pepper has been widely used for reasons that distinguish it from other chili varieties, including its more intense spiciness, stronger aroma, and distinctive color and flavor profile, making it a staple ingredient in culinary purposes [2]. Despite its broad utility, particularly in the food sector, curly red chili pepper shows a strong dependence on natural conditions. As with

all fresh agricultural commodities, curly red chili pepper possesses an inherently perishable nature, enabling it highly susceptible to food loss throughout the supply chain from upstream to downstream stages. The risk factors threatening curly red chili pepper include climate and weather variability, pest and disease outbreaks, suboptimal planting schedules, price fluctuations, harvest surplus, information distortion, mismanagement in understanding supply and demand dynamics, inadequate infrastructure and facilities, supply failures, supply-demand imbalances, and quality deterioration [3].

One of the most substantial impacts of supply chain uncertainty in curly red chili pepper is the risk of yield loss, commonly referred to as food loss. Food loss represents the reduction of food mass along the supply chain, encompassing both qualitative and quantitative dimensions [4, 5]. Food loss emerges across stages from production through marketing, prior to reaching the final consumption stage [6]. Food loss can be attributed to inadequate handling practices, technical failures, limited infrastructure, management errors, mismatches between supply and demand quantities, seasonal and climatic fluctuations, and pest and plant disease attacks. Quantitative decline in chili is predominantly caused by physical, chemical, physiological, and biological factors, resulting in losses of approximately 25–40%, while qualitative degradation is further intensified by microbial activity during the storage phase [7].

The supply chain of agricultural commodities encompasses a diverse range of actors from upstream to downstream, including farmers, collectors, wholesalers, retailers, and end consumers, making evaluation at each stage a necessary priority. Luo et al. [8] stated that supply chain evaluation is critically needed to mitigate the risk of food loss through the identification of vulnerability points and the analysis of inter-actor relationships. In the absence of adequate intervention to address yield loss, Sarangi et al. [9] elaborated on the cascading

consequences that may arise, including biodiversity loss, food security deterioration, economic damages, environmental degradation, productivity decline, resource wastage, and climate disruption. Food loss is estimated to contribute approximately 8% of total global greenhouse gas emissions, emphasizing the systemic urgency of reducing food loss risks [10].

Surakarta City emerges as an intermediary distribution location for all agricultural commodity outputs from surrounding regions, including Boyolali, Sragen, Karanganyar, Wonogiri, Klaten, and Sukoharjo, with some commodities even originating from China and the United States. Curly red chili pepper is among the commodities sourced from outside the Surakarta region that are marketed at Pasar Legi, the primary wholesale market for vegetable commodities, with the primary cultivation areas located in Cepogo, Boyolali [11]. Data from the Food Security and Agriculture Agency of Surakarta City in 2023 indicate that the consumption rate of curly red chili pepper among Surakarta residents ranks highest compared to other chili varieties. This figure is correspondingly reflected in the highest monthly community demand for curly red chili pepper relative to other varieties, amounting to 127,090.94 kg. The high dependency on external regions and a supply chain composed of multiple actors highlight the risk assessment of curly red chili pepper's supply chain in Surakarta a matter of critically required.

In the context of agricultural supply chain risk management, it is important to recognize acceptable risk limits in order to prevent risks from escalating into more severe or unmanageable conditions. In this regard, risk tolerance serves a critical role in classifying risk levels within a system. It provides a structured basis for distinguishing between risks that remain acceptable and those requiring further control and mitigation measures. [12]. Not all risks in the agricultural sector can be eliminated entirely, therefore, an approach that can distinguish between acceptable levels of risk is urgently

required. The concept of risk tolerance in food loss in the supply chain can be classified according to the severity and possibility of occurrence where the higher the risk, the more concentrated it becomes within the critical risk category. Thus, these risks are not limited to being identified but the risks will be classified into areas that are classified into several colors and levels to facilitate and improve the level of control.

Extended supply chains substantially increase the risk of food loss, requiring optimal handling practices and coordination mechanisms [11]. The various risks with potential to emerge and contribute to the probability of food loss under conditions of uncertainty must not only be identified, but also systematically evaluated and prioritized according to their probability of occurrence and magnitude of impact. Accordingly, a systematic and visually structured risk analysis approach is required to provide a comprehensive overview of risk severity within the supply chain. One applicable approach is the risk management which combines risk impact matrix and ALARP (As Low As Reasonably Practicable), in a visual format, therefore facilitating the determination of appropriate mitigation priorities. Research related to the risk impact matrix and ALARP within the domain of fresh agricultural supply chains, particularly curly red chili pepper in urban areas, remains relatively unexplored and is in considerable demand within the Indonesian scholarly landscape. This study is therefore essential as a foundational basis for understanding the dynamics of existing challenges and for formulating solutions aimed at establishing sustainability for urban communities, providing answers to how the supply chain assessment of curly red chili pepper, which has not been previously explored, can be conducted.

## **MATERIALS & METHODS**

### **Research Framework**

In this research, Surakarta was selected as the marketing city for curly red chili peppers, which originate from the Cepogo planting

area in Boyolali. The research focuses on the Pasar Legi location, which serves as the distribution area for curly red chili peppers before distributed to other sectors on a smaller scale [11]. Data were analyzed from January to March 2026, based on interviews with farmers, collectors, wholesalers, and retailers. The respondents selected from all stages of the supply chain, from upstream to downstream, including production, harvesting, postharvesting, and distribution. In this study, the main objective is to fill a gap in the process of assessing and visualizing food loss risks in the agricultural sector, particularly for curly red chili, which has not been discussed before. Evaluation using risk tolerance and visualization methods is highly required in the agricultural world because facilitating researchers understand the distribution of risks, color-coded [12]. In agricultural supply chain risk management, the integration of two assessment methods, the risk impact matrix and As Low As Reasonably Practicable (ALARP), has not been conducted before. The method in the risk impact matrix assesses risk by visualizing it in several colors to determine risk categories, which are then analyzed using ALARP to interpret risk tolerance. The ALARP approach identifies criteria for risk acceptance and tolerance thresholds and is beneficial for assessing overall risk. This is specifically due to the ALARP principle, which emphasizes the triangular balance between cost, benefit, and risk. The model is identified as a regulatory framework for assessing failures along a chain, and the risk is subsequently evaluated against a threshold value [13].

### **Risk Analysis Framework**

In this study, a risk impact matrix was applied with data from a questionnaire conducted with the respondents. The risk impact matrix in this research functions as a risk analysis tool presenting visually and mathematically complex risk data that is concise with qualitative and quantitative approaches to prioritize risks to reduce food loss and become the basis for the decision-making process [14]. The study intends to

ensure transparency in all processes, in accordance with the knowledge and mutual understanding of the actors. The risk impact matrix is a two-dimensional plot matrix of the risk consisting of the corresponding probability and consequence values (Table 1). The matrix divides risks into different risk categories, commonly labeled in color based on severity including red, yellow, and green.

The matrix groups the risks based on the level of danger generated according to the position in the matrix. The level of risk is categorized by different cell colors, for example, risks classified with red become prioritized, but without differentiating the risk with other colors present in the matrix [14, 15].

**Table 1. Risk assessment matrix adapted from ISO 31000:2018**

Probability (Occurrence)	Consequence (Severity)				
	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
5 Almost Certain	M	H	H	E	E
4 Likely	M	M	H	H	E
3 Possible	L	M	M	H	E
2 Unlikely	L	M	M	H	H
1 Rare	L	L	M	M	H

**Notes:** L: Low risk (managed by routine procedures), M: Moderate risk (specific management responsibility), H: High risk (needs attention immediately), E: Extreme risk (detailed action plan required to manage risk before progressing).

Probability is the level of probability or probability of a risk occurring in a certain system or period, while consequence is the severity or magnitude of losses that may be experienced if the risk occurs. In the risk impact matrix analysis, these two parameters are integrated to evaluate the level of risk, with risk defined as a combination of the multiplication of the probability of an event and its consequence [16]. Consequence is classified into 5 levels, ranging from insignificant to catastrophic, reflecting the severity of the impact (Table 2). The probability level is classified from rare to

almost certain which describes the probability of a risk occurring under certain conditions (Table 2). The combination of these two parameters is intended to evaluate and classify the level of risk, enabling the identification of risks that should be prioritized for mitigation without systematically underestimating other risks. The impact matrix approach is widely applied in risk analysis because it provides a systematic visual representation of complex risks in simplifying into a form of risk visualization that clearly interpreted [17].

**Table 2. Qualitative measures of probability and consequence scale or occurrence adapted from ISO 31000:2018**

Level	Probability	Scale	Description
1	Almost Certain	> 1 in 10	Expected to occur in most circumstances
2	Likely	> 1 in 10-100	Will probably occur
3	Possible	> 1 in 100-1000	Might be occurred at some time in the future
4	Unlikely	> 1 in 1000-10000	Could be occurred at some time (doubtful)
5	Rare	> 1 in 10000-100000	May occur only in exceptional circumstances
Level	Consequence	Description	
1	Insignificant	Impact or ailment not requiring treatment	
2	Minor	Minor impact or first aid treatment	
3	Moderate	Serious impact causing multiple treatment cases	
4	Major	Life threatening impact, multiple serious impact	
5	Catastrophic	Death or multiple life-threatening impact	

The ALARP tolerance assessment is an advanced evaluation of the multiplication results in the risk impact matrix method applied in this research. ALARP is a method that multiplies the results of consequence and probability in the risk impact matrix, which are then categorized into several groups. In the context of ALARP analysis, risks must be reduced to the lowest reasonable level. According to the ALARP principle, risks that fall below the tolerance threshold must still be mitigated and monitored to ensure reduced and remain relatively stable at the current level. The ALARP zone is within the range of the safe-to-accept and intolerable risk zones, separated by two acceptance and tolerance threshold lines [13]. The ALARP concept can be widely applied in high-risk areas because it requires a function to reduce

risk to the level of 'As Low as Reasonably Practicable' [18]. Risk tolerance assessment is generally categorized into three parts; acceptable (green), tolerable ALARP (yellow), and intolerable or unacceptable (red). The ALARP concept emphasizes not only about minimizing risk but also considers various perspectives in decision-making process, including value and economic benefits. This creates a good framework for beneficiaries, where the actors in the curly red chili supply chain have risks that are within reasonable limits, mitigation can be practiced and achieved when resources are available, and it is beneficial for many parties, thus the ALARP concept can be implemented as a concept with a rational, participatory, and benefit-oriented approach [18].

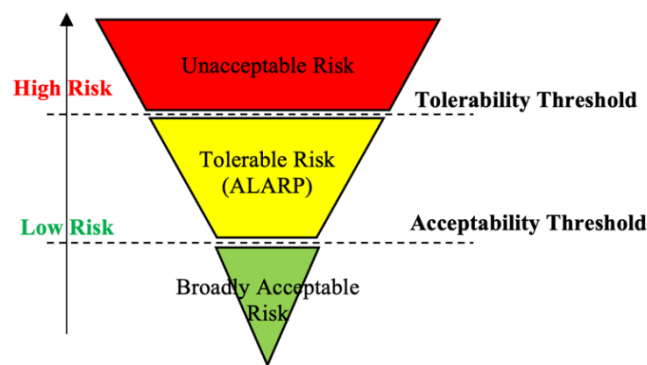


Figure 1. Risk tolerance classification triangle adapted from Maselli et al. [13]

The research by Abrahamsen et al. [19] explained that ALARP is categorized into three areas; unacceptable risk, tolerable risk (ALARP), and risk that can be neglected and does not lead to significant consequences. In the risk tolerance classification triangle, according to Hurst et al. [20], the ALARP or tolerable risk classification does not indicate complete risk acceptance. This means that the risk can be tolerated for a temporary period and properly controlled by not regarding it insignificant, and by conducting early monitoring and mitigation measures are required to reduce the risk and prevent its escalation into a high-risk category. This is a risk that is not automatically accepted; it must be continuously pursued until reaching to the lowest technically, operationally, and

economically realistic point. Risk reduction measures are important to implement, however, mitigation actions are generally not adopted when the implementation costs surpass the expected benefits. The higher zone, colored red, indicates unacceptable risk above the tolerability threshold, meaning that in this area the severity and probability are categorized as unacceptable risks. In actions within this zone, activities that pose significant risks must be immediately suppressed and reduced through mitigation measures, workflow or process changes, or, if possible, stopped or eliminated. The last zone is colored green, with an acceptable risk or no additional mitigation required because it remains below the acceptability threshold; thus, considered very low and acceptable. In

this zone, regular monitoring is needed to ensure the condition does not become more severe or spread to the next level [21]. Overall, as the level of risk increases, the obligation to reduce the risk becomes greater, whereas lower-risk levels require less extensive mitigation actions [21]. The assessment using a combination of these two methods is applied as a step to evaluate the supply chain and reduce food loss, using visual representation and tolerance limit assessment to determine the extent to which this can be achieved. This assessment is considered important because, in the agricultural world, particularly in the supply chain of curly red chili, no research has yet been revealed that evaluates based on tolerance values and risk visualization.

## RESULT AND DISCUSSION

### Curly Red Chili Peppers Supply Chain Overview

The curly red chili supply chain encounters significant risks, including food loss. This emerges from inefficiencies that have consequences for the increasing number of actors or intermediaries involved in each stage of the supply chain, the distance between distant locations, and lack of management between actors in the supply chain, therefore an evaluation of risks in the supply chain is required [22]. A study by

Delgado et al. [23] stated that food loss encompasses not only to quantity loss, but also includes product quality deterioration, which is affected by the length of the distribution chain and the low efficiency of fresh logistics. This research, illustrated in Figure 2, explains the flow of the curly red chili supply chain from upstream to downstream stages. In the study, Wigati et al. [24] explained that most actors in the chili supply chain in Indonesia have not been effectively implemented postharvest handling operational standards, specifically in the gathering, cleaning, and grading processes, therefore increasing the potential for food loss at the next stage. In addition, distributing chili peppers to wholesalers increases the risk of quality deterioration due to distribution delays, inadequate storage conditions, and unstable temperatures during distribution. Sources of food loss risk may emerge across all stages of the supply chain, from upstream to downstream. This risk emerges not only from technical production factors but also from postharvest processes, storage, distribution, market distribution, and mismatches between supply and demand. This confirms that food loss is a complex problem across each stage, influenced by the interconnectedness of activities within the agricultural supply chain [23].

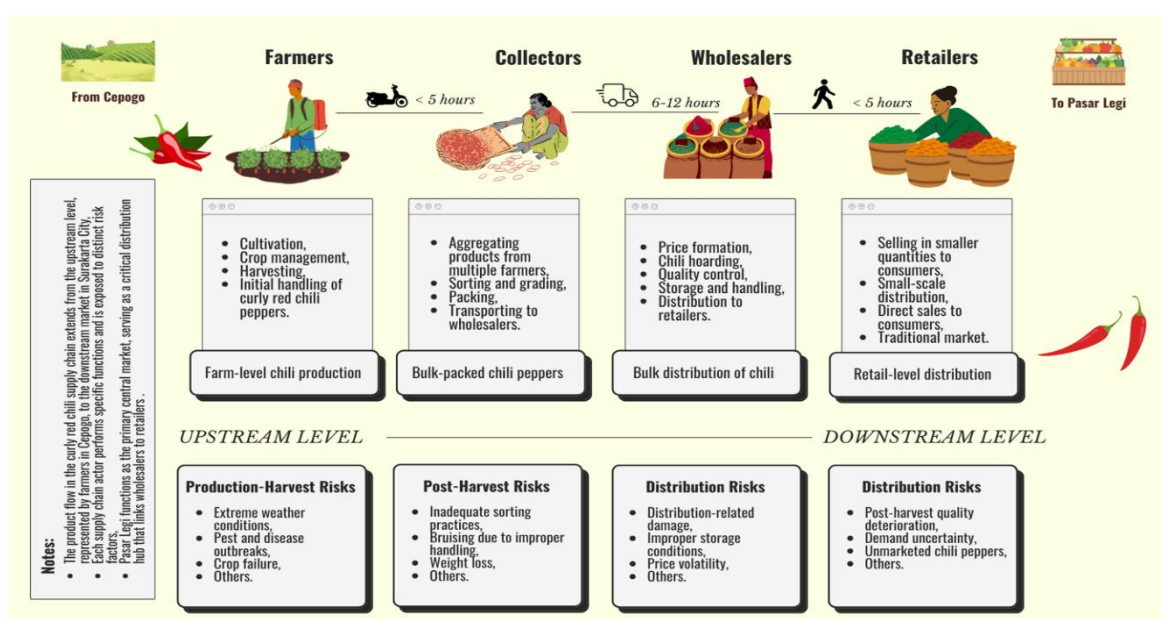


Figure 2. Supply chain mapping condition across all stages from upstream to downstream.

## Risk Management

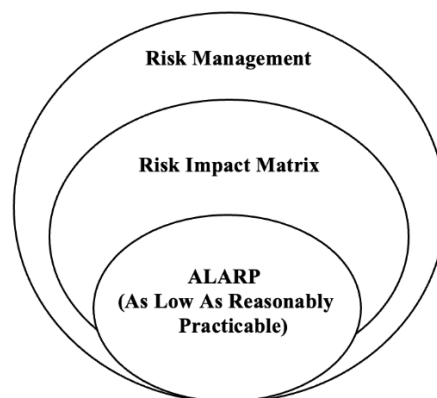
The primary aspects of risk management is the activities or actions intended for the management, regulation, stabilizing, development of opportunities as a prevention strategies for food loss. The arrangement applies a form of risk-based strategy such as risk analysis, risk mitigation, and in-depth discussions involving many parties; however, the integration of these three approaches is commonly applied in practice [19, 25]. In relation to food loss in the agricultural supply chain, risks are unavoidable, however, risks can be identified and effectively managed to reduce potential losses and avoid undesirable consequences. Risks are characterized by high volatility and continuous changes, which may the governing management model must also acknowledge the complexity of the risks by considering sustainability and benefits [26]. The opportunity for food loss in modern society is included in the new risk category. According to ISO 31000:2018 [27], there are guidelines in handling risks that consist of avoiding risks, eliminating the source of risk, changing the consequences, or maintaining risks by making informed decisions. These risk management options include tolerance, prevention, and avoidance. Conceptually, risk management can support the identification of food loss risk sources, evaluate the severity of associated risks, and develop mitigation strategies, therefore facilitating the identification of the most critical points vulnerable to food loss. The

results of the risk evaluation can be applied as a basis for decision-making to determine the right controls, such as regulating distribution systems, improving packaging quality, controlling temperature and humidity, coordination between supply chain actors, and sorting-grading in accordance with procedures [28]. Thus, the application of risk management in this study is expected to reduce economic losses, maintain chili quality, maintain supply and price stability, and sustainability of the chili supply chain in urban areas. The concept of risk management applied in this study is the main framework for risk management with all stages of the supply chain process carried out initiating from communication with all actors, risk identification, risk analysis, risk evaluation, and risk classification. Risk management in this study serves as a comprehensive framework for identifying the point at the stage of the chain and the level of tolerance of these risks that have the potential to contribute to food loss using the ISO 31000:2018 approach which positioning risk management as a systematic process to streamline and determine the sustainability of the curly red chili supply chain. Risks in the supply chain from upstream to downstream have been identified and obtained through actors and direct field observation (Table 3). These risks will vary depending on the conditions contained in each stage of the supply chain which are influenced by changing environmental and market factors.

**Table 3. Risk categories across the curly red chili supply chain from upstream to downstream**

Stages	Risk Factors
Production-Harvesting (Farmers)	P1: Seasonal-weather changes
	P2: Pest-disease attacks
	P3: Non-simultaneous planting
	P4: Lack of technological knowledge
	P5: High production costs
	P6: Lack of seed availability
	P7: Low selling price
	P8: Substandard seed quality
	P9: Improper planting area
	P10: Low production capacity
	P11: Substandard chili quality at harvest time
	P12: Inadequate harvesting facilities
Postharvesting (Collectors)	H1: Substandard chili quality

	H2: Inadequate postharvesting facilities
	H3: Improper harvesting time
	H4: Delayed distribution to wholesalers
	H5: Improper harvest handling
	H6: Distribution damaging chili quality
	H7: Inappropriate packaging or containers
	H8: Chili weight loss
	H9: Human error
	H10: Dirty or damaged sorting equipment and containers
	H11: Non-procedural handling
	H12: Improper temperature and humidity
	H13: Mismatching between chili supply and market demand
Distribution (Wholesalers)	M1: Price fluctuation
	M2: Supply depends on production
	M3: Late distribution to market
	M4: Inappropriate packaging container used (plastic/sack)
	M5: Exposure to extreme temperature and humidity during distribution
	M6: Improper handling during loading and unloading
	M7: No storage facilities (warehouse)
	M8: Storage facility (warehouse) does not comply with standards
	M9: Chili weight loss
Distribution (Retailers)	S1: Price fluctuation
	S2: Unstable chili supply
	S3: Delayed distribution schedule
	S4: Non-align to chili standards
	S5: Depends on season and weather
	S6: Market price information distortion
	S7: Improper warehouse or storage
	S8: Hoarding during price fluctuation
	S9: Delayed sales



**Figure 3. The relationship between risk management, risk impact matrix, and ALARP.**

In this study, using risk management, a combination of two methods was applied, risk matrix impact and ALARP. This integration is important because food loss in the curly red chili supply chain is influenced not only by the frequency of risk occurrence, but also by the magnitude of the consequences that emerge qualitatively and quantitatively, therefore the existence of a risk impact matrix can serve as an approach

to simplify the complexity of risk through visualization with color classification. The results of the risk impact matrix evaluation in general have been unable to directly determine whether the risk is acceptable, as the risk matrix concept primarily illustrates the severity level of risk without defining the threshold of acceptable risk tolerance. Therefore, the ALARP principle was added to be applied as an interpretation of the risk

matrix impact stage in the level of risk acceptance (Figure 3). The integration of these two methods can serve as a substantial element, therefore risk mitigation measures are not implemented excessively because later adjustments will be conducted to the level of risk that is still acceptable in the chain. The application of risk management with the topic of evaluating food loss in the agricultural supply remains very limited compared to risk management studies from the manufacturing, health, and industrial sectors [29]. The limited availability of studies highlights the importance of examining food loss in agricultural supply chains integrating the risk impact matrix and ALARP approaches in order to support supply chain actors determine effective control priorities, which are influenced by the high level of vulnerability to deteriorate during the production to distribution stages.

**Risk Assessment Analysis**

The results of the risk impact matrix analysis in this research identified that the concentration of risks at all stages of the supply chain was mainly categorized as yellow (moderate risk), with other risks in other colors: deep red (extreme risk), red (high risk), and green (low risk). Cells colored in solid red represent the highest-risk category, whereas green-colored cells indicate the lowest-risk category. Yellow cells are the cells separating green and red cells. Risks contained in the green color are generally considered tolerable or acceptable, while the hazards in the deep red group are usually considered difficult to tolerate or require immediate mitigation [30]. Cells in the yellow color category indicate the importance of additional attention is required

to reduce the risk to an acceptable minimum level (ALARP) before determining its tolerability level [31]. In the solid red cell table, there are risks of P1, P2, H8, M1, M2, M9, and S2 distributed across all stages of the supply chain (Table 4).

Chili supply chain risk mapping was illustrated by visualization based on a combination of probability and consequence values, where high risk generally emerges at high probability values ( $\geq 4$ ) followed by moderate (ALARP) to high consequence ( $\geq 3$ ) (Table 5). These risks include P1 (Changes in seasons and weather) which increasing the possibility of farmers failing to harvest and decrease the quality of chili yields as well as increasing food loss, P2 (Pest and disease attacks) which can contribute crops to be deteriorate due to quality and weight loss due to these attacks, H8 (Chili weight loss) which, when persisting, will lead to higher food loss rates, and M1 (Price fluctuations) that result in potential losses when prices drop suddenly. However, there is still a lot of supply, M2 (Supply, depending on production), where stocks are unstable and unable to meet market demand, M9 (Depreciation), which occurs when distributing from the Cepogo to Pasar Legi, and S2 (Unstable supply) when at retailers where chili peppers are overstocked, will wither quickly, rotten, and less responsive to market demand. This risk impact matrix uses the ISO 31000:2018 guideline reference regarding risk analysis that occurs with several indicators that exist in probability and consequence. In a risk table, the risk matrix represents the categories of probability (commonly on the vertical axis of the table) and consequence (commonly on the horizontal axis) [32].

**Table 4. Risk impact matrix with the probability and consequence on research.**

Probability (Occurrence)	Consequence (Severity)				
	1 Insignificant	2 Minor	3 Moderate	4 Major	5 Catastrophic
5 Almost Certain			S1	P1, P2, H8, M1, M2, M9, S2	
4 Likely		P5, P6, P7, H10, H12, S3, S4, S6	H6, H7, H9, H11, H13, M4, S5		

3 Possible	P4, H1, S7	P3, P8, P10, P11, H3, M3, M8, S8, S9	H5, M6,		
2 Unlikely	P9, P12, H2	H4, M7	M5		
1 Rare					

Risks contained in red or high risk include H6 (Delivery from the field to suppliers deteriorates the quality of chili peppers) such as bruising, breaking, or rotting faster, H7 (Improper packaging containers) will physically damage chili peppers, H9 (Human error) leading to contamination of healthy and sick chili peppers, H11 (Handling not according to procedures) can accelerate food loss, H13 (Chili is not in market demand) in case it is not appropriate, the chili will deteriorate, M4 (Unsuitable packaging container) inappropriate packaging leading to chili peppers to not circulate well rapidly deteriorate, S1 (Price fluctuations), and S5 (Chili depends on the season and weather) so that to prevent spoilage while maintaining supply stocks. In the yellow area (moderate risk) most are at the point of Likely probability with Minor consequence, such as P5 (High production cost), P6 (Seeds or seeds not available), P7 (Low selling price),

H10 (Dirty or damaged sorting equipment or containers), H12 (Inappropriate temperature and humidity), S3 (Late delivery schedule), S4 (Non-compliance of chili standards), and S6 (Market price information distortion), and on the probability of Possible with Minor to Moderate consequences. At the point of the green zone (low risk) contains only a small part of the risk such as P4 (Limited knowledge of farmers), H1 (Quality of chili when collected below standard), S7 (Storage that does not meet standards), P9 (Wrong planting location), P12 (Inadequate harvest facilities), and H2 (Inadequate collector post-harvest facilities), which reflect events with insignificant impacts (Table 5). Supply chain risk assessment and rating based on the likelihood of occurrence, severity of impact, and detection capability is an important systematic approach to ensure operational sustainability and overall supply chain performance.

**Table 5. Probability and consequence values of risks along supply chain stages**

Stages	Code	Consequence	Probability	Results
Production-Harvesting (Farmers)	P1	4	5	
	P2	4	5	
	P3	2	3	
	P4	1	3	
	P5	2	4	
	P6	2	4	
	P7	2	4	
	P8	2	3	
	P9	1	2	
	P10	2	3	
	P11	2	3	
	P12	1	2	
Postharvesting (Collectors)	H1	1	3	
	H2	1	2	
	H3	2	3	
	H4	2	2	
	H5	3	3	
	H6	3	4	
	H7	3	4	
	H8	4	5	
	H9	3	4	
	H10	2	4	
	H11	3	4	

	H12	2	4	Yellow
	H13	3	4	Red
Distribution (Wholesalers)	M1	4	5	Red
	M2	4	5	Red
	M3	2	3	Yellow
	M4	3	4	Red
	M5	3	2	Yellow
	M6	3	3	Yellow
	M7	2	2	Yellow
	M8	2	3	Yellow
	M9	4	5	Red
Distribution (Retailers)	S1	3	5	Red
	S2	4	5	Red
	S3	2	4	Yellow
	S4	2	4	Yellow
	S5	3	4	Red
	S6	2	4	Yellow
	S7	1	3	Green
	S8	2	3	Yellow
	S9	2	3	Yellow

In agricultural context, specifically horticultural commodities, the definition of color in the risk impact matrix transforms into more complex because biological and market risks and uncertainties are highly influential. Agricultural risks are not static; they evolve dynamically in response to weather factors, are highly dependent on the natural environment, and are subject to perishability and price fluctuations. Therefore, the color in the matrix not only indicates the level of risk but also describes the phase of risk evolution in an unstable system [33]. In the context of agriculture, this phase of evolution commonly emerges rapidly due to cumulative and cascading effects, or a single small disruption may have extensive or cascading impacts. This point is illustrated, for example, by distribution delays (yellow zones) or ALARP that can lead to decreased quality and unabsorbed products (red zones), which can eventually contribute to food loss. In addition, when visualized, the risk impact matrix approach also confirms that risks within a single-color category are not constantly homogeneous, due to limitations in distinguishing severity in highly complex systems [34]. This is relevant to research on agricultural commodity supply chains, which are characterized by high uncertainty and can lead to subjectivity in risk assessment and an

increased risk of priority errors when relying entirely on color categories, emphasizing the importance of the quantity of numbers in the evaluation. One of the limitations experienced in agricultural sector, specifically the supply chain of fresh agricultural commodities in this research area, the costs related to preventing these risks in the chili supply chain are considerably high. The role of the government or institutions and cooperation among all actors is crucial and required, especially farmers, in mitigating risks, therefore the reduction of food loss can be accomplished.

## CONCLUSION AND RECOMENDATION

This study demonstrates that weather changes, pest-disease infestations, improper harvesting, and demand uncertainty are critical drivers of food loss in the chili supply chain, as systematically categorized through a risk impact matrix framework and indicated by the red zone positioning in the risk impact matrix table. Classifications included in the ALARP conditions such as non-simultaneously planting, seed quality, production costs, dirty equipment, late distribution, and no storage facilities. Future research is recommended to integrate the importance of adopting an integrated risk

management approach that extends beyond upstream-downstream stages to measure the level of mitigation effectiveness of risks included in the tolerable level, supported by real-time market information, improved coordination, and adaptive, data-driven mitigation strategies.

#### **Declaration by Authors**

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#### **REFERENCES**

1. Faostat, F. A. O. Crops and livestock products. Statistics Division, Food and Agriculture Organization of the United Nations: Rome, Italy; 2022. p.50-52.
2. Taiti C, Costa C, Migliori CA, et al. Correlation between volatile compounds and spiciness in domesticated and wild fresh chili peppers. *Food and Bioprocess Technology*. 2019; 12(8): 1366–1380. DOI: <https://doi.org/10.1007/s11947-019-02297-9>
3. Dewi RK, Parining N, Harsojuwono BA. Mitigation of red chilli supply chain risks in Bali, Indonesia. *International Journal of Agriculture and Food Science*. 2023; 5(2): 103–112. DOI: <https://doi.org/10.33545/2664844X.2023.v5.i2.b.152>
4. Agnusdei GP, Coluccia B, Pacifico AM, et al. Towards circular economy in the agrifood sector: Water footprint assessment of food loss in the Italian fruit and vegetable supply chains. *Ecological Indicators*. 2022; 137: 108781. DOI: <https://doi.org/10.1016/j.ecolind.2022.108781>
5. Dora M, Biswas S, Choudhary S, et al. A system-wide interdisciplinary conceptual framework for food loss and waste mitigation strategies in the supply chain. *Industrial Marketing Management*, 2021; 93: 492–508. DOI: <https://doi.org/10.1016/j.indmarman.2020.10.013>
6. Nicastro R, Carillo P. Food loss and waste prevention strategies from farm to fork. *Sustainability*. 2021; 13(10): 5443. DOI: <https://doi.org/10.3390/su13105443>
7. Salvia E, Izhar L, Nofriati D. The various packaging effects of loker telun berasap chili damage during storage. *Indonesian Food Science & Technology Journal*. 2020; 3(2): 38–41. DOI: <https://doi.org/10.22437/iftstj.v3i2.8763>
8. Luo N, Olsen T, Liu Y, et al. Reducing food loss and waste in supply chain operations. *Transportation Research Part E: Logistics and Transportation Review*. 2022; 162: 102730. DOI: <https://doi.org/10.1016/j.tre.2022.102730>
9. Sarangi PK, Pal P, Singh AK, et al. Food waste to food security: Transition from bioresources to sustainability. *Resources*. 2024; 13(12): 164. DOI: <https://doi.org/10.3390/resources13120164>
10. Friedman-Heiman A, Miller S A. The impact of refrigeration on food losses and associated greenhouse gas emissions throughout the supply chain. *Environmental Research Letters*. 2024; 19(6): 064038. DOI: <https://doi.org/10.1088/1748-9326/ad4c7b>
11. Soepatini, Nuryulia PA, Isa M, et al. Supply-chain analysis and commodity marketing of chilli in Subosukowonosraten. *KnE Social Sciences*. 2018; 3(10): 957. DOI: <https://doi.org/10.18502/kss.v3i10.3185>
12. Høj NP, Kroon IB, Nielsen JS, et al. System risk modelling and decision-making – Reflections and common pitfalls. *Structural Safety*. 2025; 113: 102469. DOI: <https://doi.org/10.1016/j.strusafe.2024.102469>
13. Maselli G, Macchiaroli M, Nesticò A. ALARP criteria to estimate acceptability and tolerability thresholds of the investment risk. *Applied Sciences*. 2021; 11(19): 9086. DOI: <https://doi.org/10.3390/app11199086>
14. Lemmens SMP, Lopes van Balen VA, Röselaers YCM, et al. The risk matrix approach: A helpful tool weighing probability and impact when deciding on preventive and diagnostic interventions. *BMC Health Services Research*. 2022; 22(1): 218. DOI: <https://doi.org/10.1186/s12913-022-07484-7>
15. Li J, Bao C, Wu D. How to design rating schemes of risk matrices: A sequential updating approach. *Risk Analysis*. 2018; 38(1): 99–117. DOI: <https://doi.org/10.1111/risa.12810>
16. Lane K, Gagnon G. Comparing quantitative probability of occurrence to a risk matrix approach: A study of chlorine residual data. *Water Research*. 2022; 218: 118480. DOI: <https://doi.org/10.1016/j.watres.2022.118480>
17. Schwarz HV, Koerts T, Hörcher U. Semiquantitative risk analysis – An EPSC working group. *Chemical Engineering Transactions*. 2019; 77: 37–42. DOI: <https://doi.org/10.3303/CET1977007>

18. Pike H, Khan F, Amyotte P. Precautionary principle (PP) versus as low as reasonably practicable (ALARP): Which one to use and when. *Process Safety and Environmental Protection*. 2020; 137: 158–168. DOI: <https://doi.org/10.1016/j.psep.2020.02.026>
19. Abrahamsen EB, Abrahamsen HB, Milazzo MF, et al. Using the ALARP principle for safety management in the energy production sector of chemical industry. *Reliability Engineering & System Safety*. 2018; 169: 160–165. DOI: <https://doi.org/10.1016/j.ress.2017.08.014>
20. Hurst J, McIntyre J, Tamauchi Y, et al. A summary of the 'ALARP' principle and associated thinking. *Journal of Nuclear Science and Technology*. 2019; 56(2): 241–253. DOI: <https://doi.org/10.1080/00223131.2018.1551814>
21. Marhavilas PK, Koulouriotis DE. Risk-acceptance criteria in occupational health and safety risk-assessment—The state-of-the-art through a systematic literature review. *Safety*. 2021; 7(4): 77. DOI: <https://doi.org/10.3390/safety7040077>
22. Kechagias EP, Gayialis SP, Panayiotou N, et al. A holistic framework for evaluating food loss and waste due to marketing standards across the entire food supply chain. *Foods*. 2024; 13(20): 3273. DOI: <https://doi.org/10.3390/foods13203273>
23. Delgado L, Schuster M, Torero M. Quantity and quality food losses across the value Chain: A Comparative analysis. *Food Policy*. 2021; 98: 101958. DOI: <https://doi.org/10.1016/j.foodpol.2020.101958>
24. Wigati LP, Mardjan SS, Darmawati E. Post-harvest handling evaluation of red chili along the supply chain in Sukabumi. *AGROINTEK*. 2020; 14(2): 191–198. DOI: <https://doi.org/10.21107/agrointek.v14i2.5992>
25. Langdalen H, Abrahamsen EB, Selvik JT. On the importance of systems thinking when using the ALARP principle for risk management. *Reliability Engineering & System Safety*. 2020; 204: 107222. DOI: <https://doi.org/10.1016/j.ress.2020.107222>
26. Bilska B, Kołożyn-Krajewska D. Risk management of dairy product losses as a tool to improve the environment and food rescue. *Foods*. 2019; 8(10): 481. DOI: <https://doi.org/10.3390/foods8100481>
27. ISO 31000:2018 Risk Management—Guidelines; ISO: Geneva, Switzerland, 2018. Accessed from: <https://www.iso.org/obp/ui/en/#iso:std:iso:31000:ed-2:v1:en>
28. Raut RD, Gardas BB, Narwane VS, et al. Improvement in the food losses in fruits and vegetable supply chain - A perspective of cold third-party logistics approach. *Operations Research Perspectives*. 2019; 6: 100117. DOI: <https://doi.org/10.1016/j.orp.2019.100117>
29. Paillin DB, Machfud M, Hardjomidjojo H, et al. Agro-food supply chain risk assessment: A review based on technique and approach. *Journal of Applied Engineering and Technological Science (JAETS)*. 2024; 5(2): 892–908. DOI: <https://doi.org/10.37385/jaets.v5i2.3688>
30. Baybutt P. Guidelines for designing risk matrices. *Process Safety Progress*. 2018; 37(1): 49–55. DOI: <https://doi.org/10.1002/prs.11905>
31. Jensen RC, Bird RL, Nichols BW. Risk assessment matrices for workplace hazards: Design for usability. *International Journal of Environmental Research and Public Health*. 2022; 19(5): 2763. DOI: <https://doi.org/10.3390/ijerph19052763>
32. Richert M, Dudek M. Risk mapping: Ranking and analysis of selected, key risk in supply chains. *Journal of Risk and Financial Management*. 2023; 16(2). DOI: <https://doi.org/10.3390/jrfm16020071>
33. Acebes F, González-Varona JM, López-Paredes A, Pajares J. Beyond probability-impact matrices in project risk management: A quantitative methodology for risk prioritisation. *Humanities and Social Sciences Communications*. 2024; 11(1): 670. DOI: <https://doi.org/10.1057/s41599-024-03180-5>
34. Hill A, Cole R. Improving the risk matrix for supply chain risk management. *Continuity & Resilience Review*. 2025; 7(2): 166–181. DOI: <https://doi.org/10.1108/CRR-01-2025-0003>

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