

Analyzing Food Loss in Banana Pepper (*Capsicum annuum*) Production: Causes, Impact, and Challenges, A Case Study of Large-Scale Farming in the Hot District, Chiang Mai, Thailand

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Abstract

This study aimed to assess both quantitative and qualitative food loss in banana pepper production at the agricultural level. Its objectives included employing the Supply Chain Operations Reference Model (SCOR Model) for analysis, identifying root causes of losses and evaluating quantity and quality. Food loss here refers to diminished quantity and quality due to supply chain decisions and actions. Data collection and analysis included an extensive literature review, compilation of secondary data, primary data gathering via questionnaires and measurements of lost banana pepper yield during harvesting. Qualitative insights were acquired through in-depth interviews and focus group discussions. The study identified weather variability as the primary driver of food loss, with many farmers lacking access to climatic measuring tools. Additional losses, assessed visually, comprised damage from diseases, pests, stunted growth, mechanical issues and other factors, accounting for 13.68, 10.13, 6.95, 4.03 and 7.01 % of the total loss, respectively. Remarkably, only 57.93 % of the produce met quality and sale readiness criteria. The loss of banana peppers was estimated at 55.21 %, equivalent to 1,189.62 kg/rai, resulting in an economic loss of 35,688.58 Baht/rai. The study also noted significant nutrient losses, including energy, carbohydrates, fiber, protein, potassium, phosphorus, vitamin B1 and vitamin C, amounting to 321,197 kcal/rai and 57,102, 38,068, 17,844 g/rai and 3,045,427, 559,121, 487,744, 166,547 mg/rai, respectively. Farmers, while aware of food loss issues, often struggle to quantify them accurately. This study's findings can raise farmers' awareness and aid in designing training programs to mitigate such losses. However, addressing the inherent variability and unpredictability of on-farm food loss remains a challenge. Future research should prioritize a comprehensive analysis of banana pepper losses on farms.

Keywords: On-farm food loss, Banana peppers, Food loss, SCOR model, Food security

Introduction

The Food and Agriculture Organization (FAO) has defined food loss as the decrease in the quantity or quality of food resulting from decisions and actions by food suppliers in the chain, excluding retailers, food service providers and consumers [1]. By 2030, global food waste at the retail and consumer levels and food losses are targeted to be reduced to halve per capita along production and supply chains, including post-harvest losses [2]. The loss has damaged the entire economy waste of resources, loss of essential or beneficial nutrients affecting the environment both directly and indirectly. Food waste is very high in middle and high-income countries at the stage of consumption. In low-income countries, food losses occur at the beginning and middle of the food chain rather than at the consumption stage [3].

Minimizing food loss is a critical challenge in agricultural production systems worldwide. In the context of banana pepper production, efficient farmer practices play a crucial role in reducing food loss and ensuring sustainable production. This research focuses on investigating the relationship between farmer practices and the amount of food loss in banana pepper production within the large-scale farming context of the Hot District in Chiang Mai, Thailand.

Numerous studies have highlighted the impact of farmer practices on food loss across various agricultural systems. For instance, the study emphasized the importance of adopting good agricultural practices to reduce post-harvest losses and enhance food security [4]. Similarly, the research stressed the need for improved handling techniques to minimize losses and improve the nutritional quality of perishable crops. In the specific context of banana pepper production, several studies have explored the factors

influencing food loss [5]. For example, the study identified inadequate post-harvest handling practices as a significant contributor to food loss in banana production systems [6]. Another study highlighted the impact of pest and disease management on minimizing losses in banana crops [7]. However, limited research has specifically investigated the relationship between farmer practices and the amount of food loss in banana pepper production, especially in the context of large-scale farming. Understanding this relationship is crucial for developing targeted strategies to reduce food loss and enhance productivity in this sector.

Banana peppers also known as *Capsicum annuum* is a popular vegetable crop that is widely cultivated worldwide. It is known for its mild to moderately spicy flavor and is used in various culinary dishes. The production of banana peppers is prominent in several countries, contributing to the global supply of this crop. The exact production figures for banana peppers vary from year to year due to factors such as weather conditions, market demand and agricultural practices. However, some countries are known for their significant banana pepper production. One of the largest producers of banana peppers is Mexico, which has favorable climatic conditions for its cultivation. Other major producers include the United States, Spain, China, Turkey and India. These countries have established banana pepper farming systems and export their produce to meet both domestic and international demand. The global production of banana peppers reflects the popularity and consumption of this vegetable in various cuisines worldwide. The versatile nature of banana peppers, with their unique flavor and culinary applications, contributes to their consistent demand and production in many regions [8]. In the part of Thailand, banana pepper production in Thailand has gained significant importance in the agricultural sector and is cultivated extensively in various regions of Thailand. The production is concentrated in several provinces, including Chiang Mai, Chiang Rai and Lamphun. These regions have a long history of banana pepper cultivation and possess the necessary expertise and infrastructure for high-quality production. The production of banana peppers in Thailand involves various stages, including land preparation, seedling production, transplanting, cultivation, pest and disease management and harvesting. Farmers employ both traditional and modern techniques to ensure optimal growth and yield. The demand for banana peppers in Thailand is high, both in domestic markets and for export purposes. These peppers are valued for their mild to moderate spiciness and are widely used in Thai cuisine, including curries, stir-fries, salads and condiments. Government initiatives and agricultural extension programs in Thailand support banana pepper production by providing farmers with technical knowledge, training, and access to quality inputs. These efforts aim to enhance productivity, ensure sustainable practices, and meet the growing demand for banana peppers. Overall, banana pepper production in Thailand plays a crucial role in the country's agricultural sector, providing income opportunities for farmers, contributing to the economy, and satisfying the culinary preferences of consumers both within Thailand and globally.

The supply chain process reference model has been used in many case studies, the Supply Chain Operations Reference (SCOR) Model, developed by the Supply Chain Council, serves as a comprehensive framework that integrates business processes, metrics, practices, personnel and specialized applications to describe and analyze operational processes within the supply chain analyzed the import of fresh fruit business in Thailand using the supply chain operations reference SCOR model [9]. The application of the SCOR model's performance metrics in evaluating the performance of the supply chain of fruits and vegetables toward reducing losses [10]. Currently, most food loss and waste research focus on post-harvest, retail and consumer levels, where business practices, as well as consumer behavior and preferences, are the major drivers of loss but the aim of this research was on-farm food loss analysis and assessment in the banana pepper production system. In terms of food and nutrition value, the banana pepper contains several important nutrients. According to the Institute of Nutrition, Mahidol University the nutritional value of banana pepper per 100 g is as follows: Energy 27 kcal, Carbohydrates 4.8 g, Phosphorus 4.7 mg, Potassium 256 mg, Vitamin C 14 mg, Fiber 3.2 g, Protein 1.5 g, Vitamin B1 41 mg, Calcium 11 mg and Fat 0.2 g [11].

The Hot District in Chiang Mai, Thailand, is known for its large-scale banana pepper production, making it an ideal case study area. By examining the practices employed by farmers in this context, it is possible to identify the factors contributing to food loss and assess the extent of these losses. This research aims to fill the existing knowledge gap by investigating the specific relationship between farmer practices and the amount of food loss in banana pepper production in the Hot District of Chiang Mai, Thailand. By drawing insights from existing research on farmer practices, post-harvest management and pest and disease control, this study will contribute to a comprehensive understanding of the factors influencing food loss in banana pepper production. The findings will provide valuable insights to inform policymakers, farmers and other stakeholders on implementing effective measures to minimize food loss, enhance productivity and promote sustainable agricultural practices in large-scale banana pepper farming systems [12].

Studying on-farm food loss research is crucial for several reasons. Firstly, it directly impacts food security by affecting the availability of food and contributing to shortages. By understanding the factors leading to food loss, we can develop strategies to ensure a sustainable food supply. Secondly, it is essential for economic sustainability as food loss represents a significant economic loss for farmers and the agricultural sector. By identifying inefficiencies and implementing cost-effective solutions, we can improve profitability and ensure the long-term viability of farming operations. Thirdly, studying on-farm food loss helps optimize resource efficiency by reducing waste and improving the use of land, water, energy and inputs. It also addresses environmental concerns by minimizing environmental degradation associated with unnecessary resource use. Additionally, studying food loss contributes to building resilient food systems by identifying vulnerabilities and developing practices to mitigate risks. It also informs policy and intervention development, guiding investment priorities and enabling effective measures to address food loss.

The distinction of this study lies in its specific examination of banana pepper production as a case study to comprehensively assess the extent of food loss occurring on farms, encompassing aspects such as mass, nutrients and economic ramifications. Furthermore, it aims to uncover the root causes of food loss at the farm level. By focusing on banana peppers, this research offers unique insights into the broader concern of food loss, elucidating the scale of the issue and its multifaceted nature. Understanding the underlying factors contributing to food loss at the farm level is pivotal for implementing precise interventions and devising strategies to curtail these losses, optimize production and enhance the overall efficiency of the food system.

Therefore, this study was conducted with the primary objective of evaluating both the quantity and quality of food loss in banana pepper production at the farm level. Specifically, it sought to achieve 3 key aims: Firstly, to employ the SCOR Model for a comprehensive analysis of the banana pepper production system; secondly, to pinpoint the root causes of losses within banana pepper production; and thirdly, to assess the extent of loss in terms of quantity and quality. These objectives are of paramount significance in enhancing the efficiency of loss prevention and reduction within the realm of banana pepper production, as well as analogous vegetable cultivation practices. Furthermore, the study's findings hold the potential to furnish banana pepper farmers with invaluable insights into loss awareness during production processes, allowing them to make informed decisions to minimize waste and optimize yields. Moreover, the study's outcomes are poised to inform the development of strategic approaches and policy frameworks aimed at curbing substantial food losses within the context of banana pepper production in Thailand. This research contributes not only to the field of agricultural science but also to broader efforts to improve food security and sustainability in the region.

Materials and methods

Research method

This study used a mixed method with an exploratory sequential design. The mixed-method research methodology involves qualitative and quantitative approaches within the same study. The mixed method is efficient in the integration of the qualitative and quantitative results to provide an enhanced and comprehensive answer to a research question. An exploratory sequential design is a mixed methods study design, where the quantitative phase of data collection and analysis follows the qualitative phase of data collection and analysis [13]. In this study, mixed methods research offers a flexible and powerful approach, custom-tailored to the unique demands of a study. It combines qualitative and quantitative data, providing a comprehensive understanding through deep insights and statistical rigor. This approach enhances research reliability and is particularly valuable for complex inquiries requiring multifaceted exploration. Qualitative methods initiate inquiry, generating hypotheses that are rigorously tested and validated during the quantitative phase, bolstering research integrity. Moreover, it stands as a robust methodology that enriches our understanding of complex phenomena.

Study area

The case study area is in the Hot District of Chiang Mai Province **Figure 1**, home to the hot large-scale farming group. This farming group holds the distinction of being the first large-scale vegetable farming group in the province. There are 30 members of the farming group, and the total production area spans approximately 100 rai (equivalent to 39.53 acres). Historically, the group has achieved a yield of approximately 500 tons of banana pepper per crop cycle. The group's production performance typically involves 2 - 3 crop cycles per year [9]. Given these factors, this farming group presents a suitable opportunity to explore and investigate on-farm food losses.

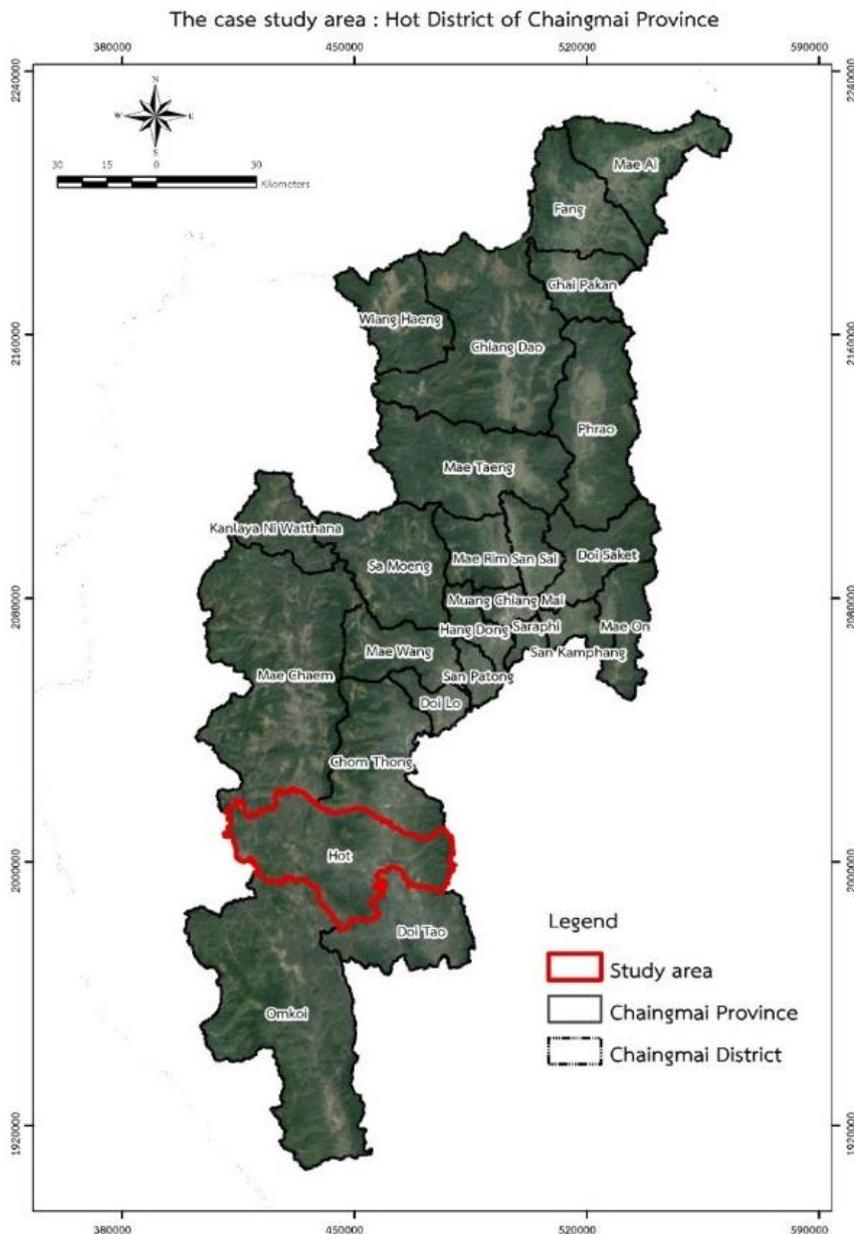


Figure 1 Map of the case study area: Hot district of Ching Mai Province.

Data collection

The survey methodology employed a combination of field visits/ observations, questionnaires, in-depth interviews and focus group discussions to gather data on the banana pepper production system, the various links within the supply chain, and how these factors contributed to losses.

A semi-structured questionnaire and focus group discussions were conducted with all 30 members of the farming group. Since this research primarily relies on fieldwork and emphasizes in-depth interviews, data collection includes all 30 participants within the small-scale group. As a result, this group serves as a representative sample for mixed-method research, primarily qualitative in nature, making this approach suitable and acceptable to a certain extent. Sample collection from farm levels has adapted the tools from Hanson *et al.* [14], which integrated the methods for determining the amount of food loss by direct weighing using a measuring device to determine the weight of food loss measurement methodology by 5 steps as follows: (1) The first step involved exploring and marking samples from 15 representative farmers’ farms using random duplicate sampling, with 3 furrows per plot; (2) In the second step, the farm owners were requested to harvest mature banana pepper that was ready for sale from the marked samples, approximately 10 banana peppers per furrow; (3) Identified banana pepper samples were categorized into 2 groups: Good

quality (with a marketable physical appearance) and inferior quality; (4) For the inferior quality group, banana pepper samples were further identified based on the causes of loss, divided into 5 groups focusing on observable symptoms, including mechanical causes, disease damage, pests damage, stunted growth and other causes; (5) The mass of loss was measured and recorded for each case, along with the mass of good quality banana pepper.

Food losses assessment;

$$\text{Percentage of the quantity of loss} = \frac{\text{Total weight of unmarketable banana pepper from samples}}{\text{Total weight of harvested samples}} \times 100$$

Total loss per rai = Average of productivity per rai × Quantity losses percent

Quality losses, which covered the economic losses and nutrient losses, were estimated as follows;

Economics losses = Market price per kilogram × Weight of losses per rai.

Nutrient losses were estimated by referring to a nutrient database of banana peppers provided by The Institute of Nutrients, Mahidol University [11]. The nutritional value of banana pepper per 100 g is as follows: Energy 27 kcal, Carbohydrates 4.8 g, Phosphorus 47 mg, Potassium 256 mg, Vitamin C 14 mg, Fiber 3.2 g, Protein 1.5 g, Vitamin B1 41 mg, Calcium 11 mg and Fat 0.2 g. For example:

$$\text{Energy losses per rai} = \frac{\text{Total loss per rai (g)} \times 27 \text{ kcal}}{100 \text{ (g)}}$$

Data analysis

Quantitative data analysis involved the utilization of descriptive statistics, including frequency, mean and percentage, conducted using the IBM SPSS Statistic version 26 software program.

Qualitative data analysis employed content analysis techniques to analyze data gathered from in-depth interviews and focus group discussions. The results derived from the data analysis serve as the foundation for proposing policy recommendations aimed at preventing and reducing losses in banana pepper production.

Result and discussion

Banana pepper production system by using the SCOR model

The SCOR Model was employed to analyze the banana pepper production system in this case study, as depicted in **Figure 2**. Through in-depth interviews and focus group discussions, several common activities were identified among the farmers, including:

Plan

Farmers typically formulated 3 distinct plans: The production plan, investment plan and market plan. In the context of the production plan, most farmers adopted a strategy of cultivating their crops twice annually, with an interval of approximately 3 months between planting cycles. The first planting cycle commenced during the dry season in November, while the second was initiated at the onset of the early rainy season in May. However, a subset of farmers deviated from this pattern by aligning their production with market demands. This subset engaged in contract farming arrangements that included price guarantees from buyers, thereby reducing their exposure to the volatility of product prices.

Regarding the investment plan, which was integral to completing the production process, it encompassed 4 primary approaches: Firstly, a significant proportion of farmers allocated half of their investment from personal resources, securing the remaining half through loans obtained from state banks, such as the Bank for Agriculture and Agricultural Cooperatives. Secondly, some farmers committed their entire financial resources to the endeavor. Thirdly, a smaller cohort of farmers resorted to borrowing funds from relatives. Lastly, certain farmers adopted a mixed strategy, utilizing a portion of their own capital and securing credit to procure fertilizer or pesticide, with repayment deferred until after the crop's harvest, often facilitated through chemical fertilizer stores.

Finally, with respect to the market plan, the prevailing practice among most farmers was characterized by an absence of concrete marketing strategies until the approaching harvest season. During this period,

prospective buyers from the same community or neighboring areas conducted product inspections and negotiated reservations based on mutually agreeable prices. In contrast, some farmers operated within the framework of contract farming agreements, shielding them from market-related uncertainties and obviating the need for direct market engagement.

Source

The various production factors essential for agricultural activities, including fertilizers, pesticides, seedlings, manures and supplements, were distributed to small and medium-scale producers through a network of numerous informal businesses situated in nearby districts or villages, each of which typically operated multiple stores, numbering more than 5 in several instances. These businesses commonly employed sales agents who engaged directly with local producers, promoting and selling their agricultural inputs. However, it should be noted that certain microbial pesticides were occasionally produced by farmers themselves.

Conversely, farm machinery and equipment, such as small tractors, were typically procured from urban centers, particularly from the downtown area of Muang Chiang Mai. Lastly, labor forces engaged in agricultural production among large-scale producers encompassed both permanent and seasonal laborers, with permanent laborers often originating from distant villages or neighboring countries. In contrast, small-scale producers predominantly relied on family labor, occasionally supplementing their workforce by hiring seasonal labor from within their village.

Make

Seed selection focused on a germination rate of 80 % or more, suitability for the planting area's environment, and marketability.

Furrow preparation began with plowing the field, followed by a 7-day sun-drying period. Subsequently, urea and cow manure were applied to augment soil fertility. After the completion of this 7-day period, furrows were established, typically raised to a height of approximately 15 - 20 cm above ground level, with spacing of 30 - 40 cm maintained between individual plants. The length of each furrow varied between 15 to 30 m, contingent upon the specific dimensions of the land plot. Ultimately, the furrows were covered with plastic sheeting.

In the context of plant propagation, farmers were presented with 2 primary alternatives for acquiring seedlings. The first alternative entailed the selection of high-quality seeds, followed by independent seed breeding within trays over a 1-month period. The second alternative involved procuring seedlings from a nearby nursery. Nevertheless, a significant proportion of farmers opted for the former option, cultivating their own seedlings. This preference was primarily driven by the desire for enhanced control over the quality of the resultant seedlings, a factor deemed pivotal in their decision-making process.

In the planting and care phase, the predominant practice among farmers involved cultivating banana peppers in open fields rather than within greenhouses. An overarching concern shared by all farmers pertained to the occurrence of drought and resultant dehydration risks. Consequently, proactive measures were taken in the form of on-farm water reservoirs to address this issue, albeit certain seasons witnessed extreme aridity that challenged the adequacy of the water supply. To counteract this challenge, some farmers employed water pumping mechanisms to irrigate the furrows, frequently complemented by the utilization of drip irrigation systems to optimize water conservation. The irrigation schedule was characterized by a weekly water provision routine, with additional manual watering using watering cans deployed in instances of excessive aridity. Furthermore, year-round availability of water reservoirs was maintained. Regarding fertilization practices, farmers commenced fertilization 7 days after planting, applying a balanced fertilizer, and subsequently repeating this process every 10 days. During the 60-day stage leading up to harvest, a 13-13-21 fertilizer was administered every 10 days. Additionally, during the 30-day stage, measures were taken to mitigate aphid infestations, and in cases of high humidity, aphid-killing sprays were employed as a preventive measure.

In the context of weed control strategies, a significant proportion of farmers adopted the practice of utilizing plastic mulch to cover the furrows. Additionally, some farmers opted for cost-saving measures by manually cutting grass as a means of weed control. To enhance the quality of their banana pepper crops, farmers employed a combination of chemical fertilizers, organic manures and diverse supplements in their cultivation practices. Pesticide control and prevention: The effective management of pesticide utilization and prevention strategies is largely contingent upon strict adherence to the Good Agriculture Practice (GAP) standard, which functions as the principal framework guiding pesticide selection. As a result, farmers exercise judicious discretion in determining the specific chemical pesticides to employ, alongside the meticulous consideration of application duration, in order to maintain pesticide residues within

predefined thresholds. Furthermore, a subset of farmers possesses the capability to manufacture and utilize biopesticides, thereby contributing to the control and protection of crops against plant pathogens.

Regarding weather variability, a prevailing trend among farmers was the absence of proactive strategies aimed at mitigating its effects or responding to immediate challenges arising from its influence. Consequently, this lack of proactive planning translated into an inability to effectively address issues related to plant growth and crop quality resulting from the unpredictability of weather conditions.

The harvesting phase typically commenced approximately 80 - 90 days after the initial planting, a period coinciding with the emergence of approximately 10 % of the flowers transitioning into a red hue. The precise timing of the harvest, however, was contingent upon market dynamics and the demand for either red or green peppers, necessitating a degree of flexibility in the harvesting schedule. This harvesting process spanned a duration of 10 - 15 days per cycle. The methodology employed for harvesting involved manual labor, with peppers being collected into buckets or baskets. Subsequently, the harvested produce underwent sorting and packaging procedures, with a notable practice being the avoidance of washing at this stage.

In the grading phase, the harvested peppers were meticulously sorted into distinct grades, typically ranging from 1 to 2 categories. A notable criterion for differentiation was the selection of short and curved peppers, which were earmarked for separate pricing consideration. Concurrently, an essential aspect of this process involved the rigorous evaluation and identification of unusable produce, particularly those afflicted by damage caused by insects or diseases. Such produce was systematically rejected from the grading process, ensuring that only peppers meeting the requisite quality standards proceeded for further distribution and marketing.

In the packing phase, following the meticulous sorting process, the harvested produce was carefully arranged within baskets and subsequently stored in a suitable dry environment, in preparation for distribution.

Delivery

The packaging process involved placing the produce in baskets, which were then transported by pickup trucks to be sold in local markets within the community. Subsequently, a grading procedure was implemented, and products failing to meet the predetermined quality standards, accounting for approximately 10 - 15 % of the total yield, were identified for exclusion. Prior to harvesting, negotiations concerning pricing were conducted via telephone discussions, with agreements reached beforehand. Should the produce have met the specified quality criteria, it was subsequently purchased at the pre-agreed price.

Return

There was no provision for product returns if the quality did not meet the specifications set by the buyer. In such cases, the produce underwent a regrading process, accompanied by a reduction in the purchase price, typically ranging from 1 to 3 Baht per kg. Alternatively, if an agreement on the purchase price could not be reached, farmers had the option to sell the produce independently in local community markets or through retail vendors.

The application of the SCOR model in this study has yielded significant insights into the banana pepper production system. These findings not only serve to identify areas for potential workflow optimization but also contribute substantively to the overarching goal of food loss reduction management. The utility of the SCOR model in precisely delineating the extent and underlying causes of food loss is underscored by our results. This echoes previous research endeavors conducted by various scholars who have also lauded the efficacy of the SCOR model in appraising and addressing food loss concerns. Our study, employing this model, meticulously unravels the vulnerabilities within each stage of banana pepper production at the farm level. Of note, it becomes apparent from our findings that a significant proportion of farmers lack preemptive strategies to mitigate the impact of inclement weather or to promptly address the challenges posed by unpredictable weather conditions [15-17].

Furthermore, the SCOR model has demonstrated its versatility and effectiveness in the realm of agriculture supply chain analysis, as evidenced by its application in various contexts, including the evaluation of the floricultural sector's performance and the assessment of challenges within the chilled fresh fruit importation supply chain. These applications underscore the model's capacity to categorize companies, offer insights into sector-wide performance and provide valuable guidance for improving supply chain management. By assisting managers, consultants, industries and governments in addressing performance issues, implementing optimization strategies and embracing technological advancements, the SCOR model plays a pivotal role in enhancing the competitiveness of agricultural supply chains in the global market [18].

In sum, this research extends its utility beyond its immediate scope and holds relevance for stakeholders across the supply chain, offering valuable insights into mitigating food loss throughout the entirety of the supply chain.



Figure 2 The banana pepper production system utilizing the SCOR model.

Identify causes of loss in banana pepper production

The results presented in **Table 1** and **Figure 2** indicate that the main factor influencing banana pepper losses among farmers is weather variability, with a practice level of 2.083, indicating occasional practice. This suggests that farmers rarely utilize tools such as hygrometers, temperature gauges and rain gauges to control and monitor the climate in their planting areas. Moreover, the farmers had low competency to solve problems of plant growth and crop quality caused by inclement weather. Afterward, funding and funding source is the level of practice by 3.49 which means moderate practice. Eventually, the other issues namely natural disasters, cultivation and maintenance, cleanliness and standards of the collecting and packing place, production plan, farmers' knowledge and skills, workers, diseases and pests, tools and harvesting method, cleaning and trimming of produce before packing, harvest time, sprouts or seeds, transportation of products from the farm to the collecting and packing place both of them are in a lot of practice level by 3.642, 3.859, 3.900, 3.933, 4.167, 4.200, 4.256, 4.283, 4.367, 4.383, 4.389 and 4.422, respectively.

During the focus group discussions, farmers mentioned that when the temperature is higher than normal, they must increase water irrigation to maintain a balanced temperature in the field. However, if the temperature becomes uncontrollable, the excessive heat adversely affects the growth of the banana pepper, leading to stunted growth. Additionally, weather variability also contributes to increased susceptibility to plant diseases, which are more challenging to control under such conditions. In some cases, farmers may need to resort to crop destruction to prevent the spread of diseases.

Table 1 The level of farmers' practices affecting Banana Pepper production systems.

Issues and procedures	Level of practice	Meaning of practice level	Std. deviation
1. Weather variability	2.083	Sometime practice	0.740
2. Funding and Funding source	3.489	Moderate practice	0.913
3. Natural disasters	3.642	A lot of practice	0.759
4. Cultivation and maintenance	3.859	A lot of practice	0.635
5. Cleanliness and standards of the collecting and packing place	3.900	A lot of practice	0.598
6. Production plan	3.933	A lot of practice	1.009
7. Farmers' knowledge and skills	4.167	A lot of practice	0.781
8. Workers	4.200	A lot of practice	0.552
9. Diseases and pests	4.256	A lot of practice	0.611
10. Tools and harvesting method	4.283	A lot of practice	0.612
11. Cleaning and trimming of produce before packing	4.367	A lot of practice	0.865
12. Harvest time	4.383	A lot of practice	0.916
13. Sprouts or seeds	4.389	A lot of practice	0.714
14. Transportation of products from the farm to the collecting and packing place	4.422	A lot of practice	0.946

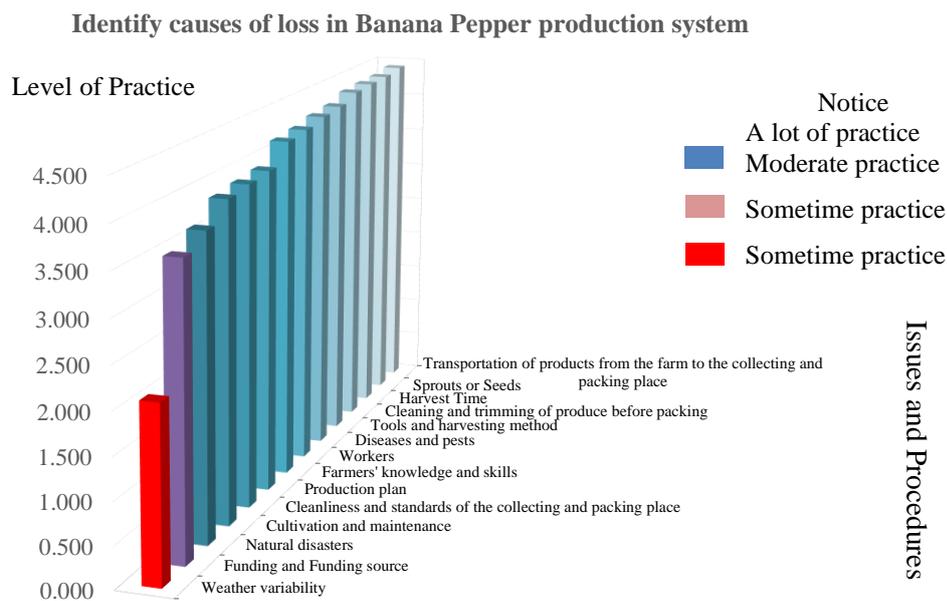


Figure 3 Identify causes of loss in the banana pepper production system.

The losses of banana pepper in terms of both quantity and quality at the farm level

Quantity of losses assessment in terms of mass from farm level as the harvesting stage. Data presented in Table 2 show banana pepper losses amounted to 1,189.62 kg per rai or 55.21 %

Table 2 Mass of banana pepper losses at the farm level.

Mass of losses	Quantity
Average yield production per rai	2,154.72 kg/rai
Total sample weight	3,088.33 g
Total weight of losses	1,705.13 kg
Percent of losses (100×1,705.13 kg)/3,088.33 kg	55.21 %
Total weight of losses per rai (2,154.72×55.21)/100 kg	1,189.62 kg

Figure 4 presents a visual assessment identified that 4.30 % of the total product was lost due to mechanical causes, 13.68 % due to disease damage, 10.13 % due to pests damage, 6.95 % due to stunted growth and 7.01 % due to other causes. Consequently, only 57.93 % of the total product was deemed of good quality and ready for sale.

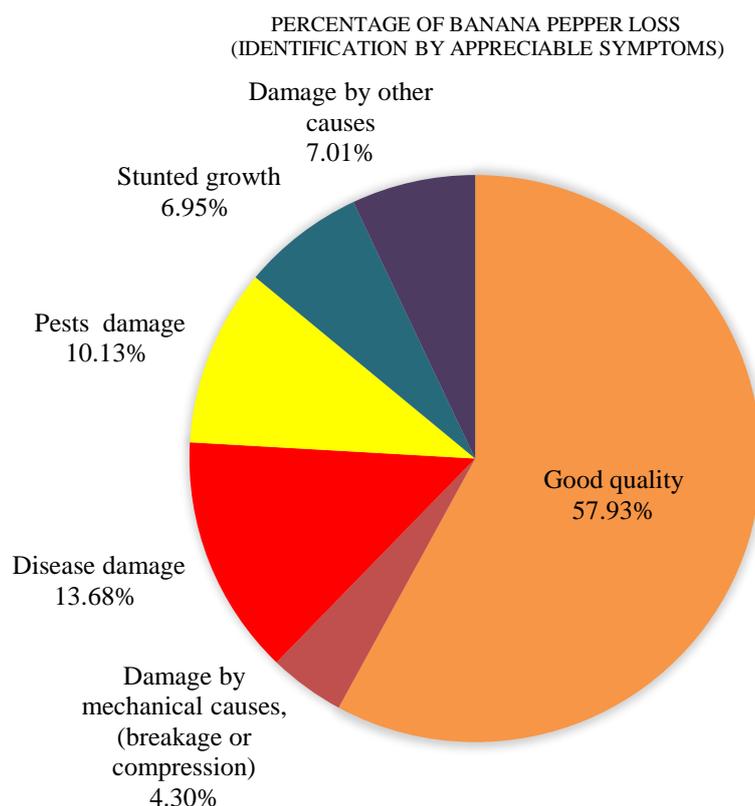


Figure 4 Percentage of banana pepper loss (Identification by appreciable symptoms).

The assessment of banana pepper losses encompasses both economic and nutrient aspects. Based on the average yield production of 4,854 kg/rai, as shown in **Table 3**, the assessment considers the market price per kilogram, which is referenced from the Taladthai market in August 2022 [19] is around 30 Baht/kg. The economic loss for banana pepper was approximately 35,688.58 Baht/rai.

Table 3 Economics of banana pepper losses.

Economic losses	Quantity
Average yield production per rai	2,154.72 kg/rai
The average market price per kilogram (Reference from Talaadthai market in August 2022)	30.00 Baht/kg
Total weight of losses per rai	1,189.62 kg
Economics losses (1,189.62 kg×30 Baht/kg)	35,688.58 Baht/rai

Table 4 presents the assessment of nutrient losses per rai, calculated based on the average yield production referenced in **Table 3**, which amounted to a loss of 1,189.62 kg/rai. The results of the assessment further indicate significant nutrient losses in the form of energy: 321,197 kcal/rai, carbohydrates: 57,102 g/rai, fiber: 38,068 g/rai, protein: 17,844 g/rai, potassium: 3,045,427 mg/rai, phosphorus: 559,121 mg/rai, Vitamin B1: 487,744 mg/rai and Vitamin C: 166,547 mg/rai. These findings underscore the considerable nutrient losses incurred during banana pepper production.

Table 4 Nutrient of banana pepper losses assessment.

Nutrients	Detail	Content per 100 g edible portion	Nutrient loss per rai
Energy, by calculation	Calculated by (4×g protein) + (9×g fat) + (4×g CHOAVLDF) + (2×g dietary fibre) (not include alcohol)	27 kcal	321,197 kcal
Carbohydrate, available	Calculated by difference: CHOAVLDF = 100 – (weight in g [water + protein + fat + dietary fiber + ash] in 100 g food)	4.8 g	57,102 g
Fiber	AOAC method	3.2 g	38,068 g
Protein, total		1.5 g	17,844 g
Potassium	AOAC method	256 mg	3,045,427 mg
Phosphorus	AOAC method	47 mg	559,121 mg
Vitamin B1	AOAC - HPLC method	41 mg	487,744 mg
Vitamin C	AOAC - HPLC method	14 mg	166,547 mg

Note: Total weight of losses 1,189.62 kg/rai

The analysis of data in **Figure 3** underscores that weather variability stands out as the predominant cause of banana pepper losses at the farm level, with farmers infrequently employing climate control tools in their planting areas. This factor significantly impacts farming practices, leading to increased banana pepper losses. Corroborating this finding, previous research conducted by scholars in various agricultural contexts has also identified weather variability as a primary contributor to food losses in the production of fruits and vegetables and crop yield losses in agriculture, respectively [20,21]. These studies are congruent with the findings of postharvest management and its influence on quantity and quality losses of leafy vegetables, highlighting the role of external factors such as temperature, humidity, atmospheric composition, light and pests in causing losses [22]. Furthermore, the data obtained from field sampling elucidate the primary causes of losses, discerned through visual symptoms. These findings resonate with postharvest losses of vegetables in the Royal Project Foundation and identified underutilized portions of vegetables, insect damage and mechanical injury as key causes of loss [23]. Similarly, a study on reducing vegetable productivity loss in the highland fields of the Royal Project Foundation, delineating 3 stages of loss. The pre-harvest stage encompassed poor-quality products, disease and insect infestations, weather variability, natural disasters and recessive species. The harvesting stage implicated product damage due to improper harvesting methods and equipment, as well as product shrinkage stemming from suboptimal harvesting timing, lack of post-harvest management knowledge and technological deficiencies. Lastly, the post-harvest stage involved product bruising resulting from packaging, container handling and inefficient transportation from the farm to the packing facility [24].

In summary, the present study aligns with existing research in identifying weather variability as a predominant cause of banana pepper losses at the farm level. Additionally, the analysis underscores the multifaceted nature of losses, encompassing mechanical, disease, pest-related and growth-related factors. These findings offer valuable insights for addressing food loss reduction strategies in banana pepper production and highlight the importance of holistic approaches to mitigate losses throughout the production process.

This study, despite its focus on banana pepper production, which may not represent a major economic vegetable crop, offers valuable insights for comparative analysis of food loss within the production process. It highlights substantial challenges associated with accurate quantification of on-farm food losses. These challenges result from a convergence of factors, notably the limited availability of tools and resources for meticulous loss monitoring and documentation. Moreover, the heterogeneous nature of on-farm food loss, stemming from a myriad of factors and occurring at various production stages, exacerbates the challenge of precise quantification. Consequently, disparities often arise between farmers' actual losses and their subjective estimations, influencing their decision-making processes and potentially hindering effective mitigation strategies. However, the study's findings hold the potential to increase awareness among farmers and stakeholders regarding the significance of on-farm food loss. This heightened awareness can catalyze initiatives, including tailored training programs, to equip farmers with the necessary knowledge and

practical tools for mitigating losses, improving crop management practices and enhancing agricultural productivity. Nonetheless, addressing the inherent variability of on-farm food loss remains a pervasive challenge. This variability, contingent on a range of factors including local climate, crop diversity, farming methods and resource access, necessitates the development of adaptable, context-specific interventions. Additionally, the ever-evolving external influences on on-farm food loss, such as changing weather patterns and evolving pest and disease dynamics, present an ongoing and multifaceted challenge requiring the pursuit of sustainable and resilient strategies by agricultural policymakers and practitioners.

Conclusions

The study's analysis concluded that weather variability was the primary contributing factor to food loss among banana pepper farmers, a situation exacerbated by the absence of essential climatic measuring tools. Furthermore, visual assessments revealed substantial losses attributed to various factors, including diseases, pests, stunted growth and mechanical issues, collectively accounting for a significant portion of the overall loss. Notably, a noteworthy percentage of the banana peppers produced fell short of meeting the quality and sale readiness criteria, resulting in substantial economic and nutrient losses, including Energy, Carbohydrates, Fiber, Protein, Potassium, Phosphorus, Vitamin B1 and Vitamin C. Nonetheless, the study had limitations, including its regional focus, which may limit generalizability. It also did not thoroughly explore broader climate change implications or conduct an in-depth examination of nutrient analysis at the farm level. Nevertheless, future research holds promise in informing policies and strategies to address food loss in banana pepper production, underscoring the necessity for a broader scope, enhanced data collection, and innovative mitigation approaches.

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