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Evaluation of the Causes of On-Farm Food Loss in Cabbage Production: A Case Study in the Large-Scale Farming Group of Hot District, Chiang Mai, Thailand

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ABSTRACT

Food loss at the production stage presents significant economic and environmental challenges, particularly in horticultural systems. This study investigates the extent, causes, and impacts of food loss in cabbage production. Weather variability was identified as the primary driver affecting yield quality. Symptom analysis revealed that 24% of losses were due to produce not meeting size requirements, 23% to excessive leaf trimming, 13% to pest and disease damage, and 6% to stunted growth, resulting in only 34% of total production being marketable. The total loss recorded was 66.58%, equivalent to 3,231.79 kg/rai (1 rai = 0.16 ha), corresponding to an economic loss of approximately 105,033 Baht/rai. In addition, considerable nutrient losses were observed, including energy, carbohydrates, key minerals such as potassium, phosphorus, calcium, and sodium, and vitamin C. These losses indicate substantial inefficiencies in resource utilisation and increased environmental burden. The findings highlight the need for improved production management and targeted interventions to reduce losses. Strengthening farmer awareness and adopting better agronomic practices are essential to enhance productivity, reduce environmental impacts, and support sustainable agriculture and food security.

Keywords: Cabbage loss analysis, farming group, food loss, on-farm food loss

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INTRODUCTION

Utilising the entire crop yield could enhance production without increasing land or chemical input usage (Pellegrini & Fernández, 2018). This approach suggests that mitigating farm-level losses may offer a pathway to sustainable intensification, defined as increasing food production without exacerbating environmental impacts (Johnson et al., 2018). Food loss, often unintentional, results from various constraints in agricultural production, such as market conditions or weather effects on produce quality (Gillman et al., 2019). It leads to the waste of resources, including water, land, fuel, fertiliser, and agricultural chemicals, which may be used inefficiently in agricultural processes or during food processing and disposal (Campbell & Munden-Dixon, 2018). Traditionally, efforts to ensure food security have focused on augmenting crop yields, with vegetable producers continually striving to maximise output through improved varieties, tailored fertility programs, precise irrigation, and sophisticated pest and disease management strategies. An alternative approach to augmenting food availability involves reducing losses and enhancing sustainability (Winans et al., 2020). Frequently, produce remains unharvested in fields if it fails to meet market standards or if market prices are too low to justify the cost of harvesting. Like food loss at other stages of the supply chain, farm-level food loss contributes to climate change, pollution, excessive utilisation of water and agricultural chemicals, loss of ecosystem services, and encroachment on critical habitats (Baker et al., 2019).

The Food and Agriculture Organisation (FAO) defines food loss as a decrease in the quantity or quality of food resulting from decisions and actions by suppliers within the supply chain, excluding retailers, food service providers, and consumers. By 2030, it is projected that global food waste at retail and consumer levels, along with post-harvest losses, will be halved per capita across production and supply chains (Carlsen & Bruggemann, 2021; Parfitt et al., 2010). Food loss has significant detrimental effects on the global economy. Food waste is particularly prevalent in middle and high-income countries at the consumption stage. In contrast, in low-income countries, food losses predominantly occur at the early and middle stages of the food chain, rather than at the consumption stage. Globally, production processes account for 24-30% of food loss and waste (FLW), post-harvest losses for 20%, and consumption for 30-35% of the total FLW (Kummu et al., 2012; Lipinski et al., 2013). In low-income countries, overplanting is a notable contributor to food loss. Additionally, in these regions, food losses are often due to inadequate infrastructure, including inefficient equipment and insufficient cold storage, further exacerbating food insecurity. In Southeast Asia, countries like Vietnam, Malaysia, Thailand, the Philippines, and Indonesia experience significant fruit and vegetable losses ranging from 14% to 42%. The primary causes of productivity losses at the post-harvest stage include: (1) storage processes that involve collection during both mature and immature periods, and handling that may cause damage; (2) accelerated trimming and washing processes, where rapid

cleaning can exacerbate injuries to the produce; (3) packaging issues, including losses during sorting and the use of low-quality materials; (4) insufficient cold storage, leading to spoilage; (5) mechanical damage and congestion during transport; and (6) marketplace conditions, where high temperatures can dehydrate the products (Chinwang et al., 2011).

Globally, approximately 70,150,406 tons of cabbage are produced annually. China is the world's largest cabbage producer, producing 34,151,665 tons annually. India follows with an annual production of 9,127,000 tons. Together, China and India account for over 60% of global cabbage production. Thailand ranks 30th, producing 221,679 tons annually. In 2023, Thailand's cabbage yield was about 60,020 tons from a cultivated area of 29,289 rai, averaging 2,943 kg/rai. The average market price for cabbage was 5.31 Baht per kilogram. Chiang Mai Province, as Thailand's second-largest cabbage producer, yielded around 11,620 tons. The Hot District in Chiang Mai is home to the region's largest vegetable farming cooperative, which comprises 30 farmer members and spans 100 rai. This group primarily grows tomatoes, banana peppers, and cabbage, achieving notable yields of approximately 500 tons of cabbage, 400 tons of chillies, and 500 tons of tomatoes per crop cycle. The cooperative manages to conduct 2-3 crop cycles each year, demonstrating impressive production performance (Atlas Big, 2023; Department of Agricultural Extension, 2022).

Despite their achievements, the farming group faces several challenges. They lack the necessary knowledge and resources for implementing technology to control greenhouse conditions. Limited capital restricts their ability to invest in advanced harvesting equipment that could significantly improve production and product quality. Additionally, there is a scarcity of equipment essential for harvesting, storage, and improving product conditions, such as grading and packing. These limitations hinder the group's potential to enhance production efficiency and product quality. Production losses have been identified at various stages, including harvesting, handling, grading, packaging, and storage of agricultural products (Chiang Mai Agricultural Extension Office, 2019).

In Thailand, extensive research has been conducted on on-farm food loss, particularly in vegetable production. However, there remains a lack of precise data on estimating food losses in both quantity and quality. Farmers require additional knowledge, technologies, and models to effectively quantify food losses and implement strategies to prevent and reduce pre-harvest and post-harvest losses. Despite recognising the issue of food loss, many farmers struggle to determine the extent of losses occurring in each production stage.

Therefore, this study was conducted to assess the quantity and quality of cabbage food loss at the farm level. The study aimed to identify the causes of losses in cabbage production and evaluate losses in cabbage quantity and quality. These findings are crucial for improving the efficiency of loss prevention and reducing cabbage production. Furthermore, the results from this study will provide cabbage farmers with insights into production losses, aiding the development of strategies and policies to better handle cabbage and prevent significant losses in Thailand.

METHODOLOGY

Method Approach

This study employed a mixed-method approach using an exploratory sequential design. Mixed-method research integrates qualitative and quantitative methodologies within a single study, combining their findings to deliver a more comprehensive response to the research question. An exploratory sequential design is a specific type of mixed-methods framework in which the quantitative phase of data collection and analysis follows the qualitative phase, enabling systematic exploration and subsequent quantification of the research topic (Creswell & Creswell, 2017).

Study Area

The case study is in the Hot District of Chiang Mai Province, home to the pioneering large-scale Hot farming group. This group is the first of its kind in large-scale vegetable production in the province. It operates over an area of approximately 100 rai (16 hectares). Historically, this group has consistently achieved a yield of about 500 tons of cabbage per crop cycle. With 2-3 crop cycles conducted annually, this farming group offers an excellent opportunity to explore and investigate on-farm food losses (Chiang Mai Agricultural Extension Office, 2019).

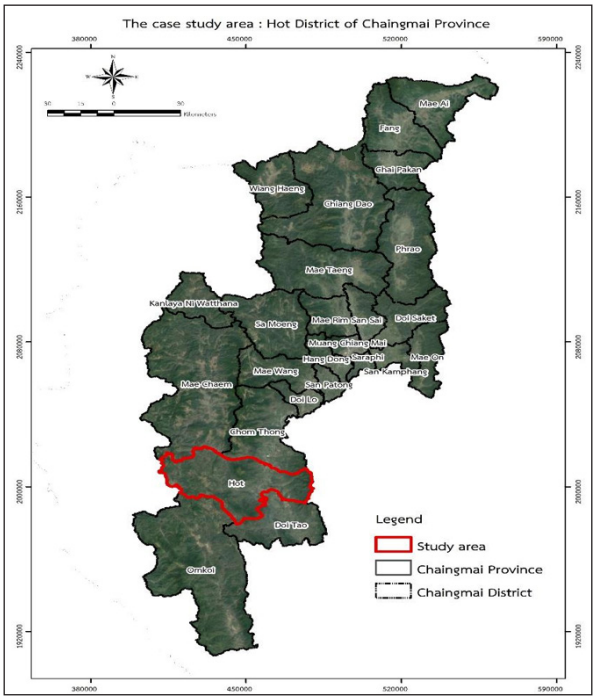

Figure 1. Map of the case study area: The hot district of Chiang Mai Province

Data Collection

The survey methodology combined field visits, observations, questionnaires, in-depth interviews, and focus group discussions to collect data on the cabbage production system, its supply chain, and the factors contributing to losses.

A semi-structured questionnaire and focus group discussions were conducted with all 30 members of the farming groups. This method was instrumental in identifying the causes of loss in cabbage production and understanding how these causes relate to food loss at various stages of the production process. The sample collection from farm levels employed tools, integrating methods to quantify food loss through direct weighing with a measuring device, structured into five steps (Hanson et al., 2016):

1. Initially, samples were selected from 15 representative farms using random duplicate sampling, marking 3 furrows per plot.
2. Farmers were then asked to harvest mature cabbages ready for sale from these marked samples, approximately 10 cabbages per furrow.
3. Harvested cabbage samples were categorised into two groups: those of marketable quality and those of inferior quality.
4. Cabbages of inferior quality were further classified based on the causes of loss, divided into four categories focused on observable symptoms: damage from pests and disease, unmarketable size, small and stunted growth, and trimmed leaves.
5. Finally, the mass of the lost produce was measured and recorded for each category, along with the mass of the good-quality cabbages.

Food Losses Assessment

The percentage of quantity loss was calculated using Equation 1, while the total loss per rai was calculated using Equation 2.

$$Percentage\ of\ the\ quantity\ of\ loss = \frac{total\ weight\ of\ unmarketable\ cabbage\ from\ samples\ x\ 100}{total\ weight\ of\ harvested\ samples} \quad [1]$$

$$Total\ loss\ per\ rai = average\ of\ productivity\ per\ rai\ x\ quantity\ losses\ percent \quad [2]$$

Quality losses, which included economic and nutrient losses, were estimated as follows. Economic losses were calculated using Equation 3.

$$Economic\ losses = market\ price\ per\ kilogram\ x\ the\ weight\ of\ losses\ per\ rai \quad [3]$$

Nutrient losses were estimated using a cabbage nutrient database provided by the Institute of Nutrient, Mahidol University. The nutrient content was compiled per 100-gram edible portion and included the following values: energy (24 kilocalories), carbohydrates (3.24 grams), potassium (236 milligrams), phosphorus (36 milligrams), calcium (34 milligrams), and vitamin C (19 milligrams) (Judprasong et al., 2015). For example, energy loss per rai was calculated using Equation 4.

$$Energy\ losses\ per\ rai = \frac{total\ loss\ per\ rai\ (g) x\ 24kcal}{100\ (g)} \quad [4]$$

Data Analysis

Quantitative data analysis was conducted using descriptive statistics, including frequencies, means, and percentages, utilising IBM SPSS version 26. Qualitative data analysis involved employing content analysis techniques to examine data collected from in-depth interviews and focus group discussions. The findings from these analyses provide a solid basis for formulating policy recommendations to prevent and reduce losses in cabbage production.

The evaluation of practices contributing to food loss during cabbage production was conducted through structured interviews. These interviews addressed fourteen aspects, organised into two phases: production and post-production. The production phase included: (1) production planning, (2) funding and funding sources, (3) sprouts and seeds, (4) cultivation and maintenance, (5) disease and pests, (6) weather variability, (7) natural disasters, and (8) farmers' knowledge and skills. The post-production phase covered: (9) tools and harvesting methods, (10) transportation of produce from the farm to collection and packing sites, (11) Cleanliness and standards of the collecting and packing place, (12) harvest time, (13) workers, and (14) cleaning and trimming of produce before packing. Farmers' adherence to these practices was assessed using a five-point Likert scale, where 5 indicates the highest level of adherence and 1 the lowest. These scores were averaged and compared against a predefined set of interpretative criteria divided into five intervals, each spanning 0.50 points. Average scores were interpreted as follows: 4.51-5.00 represents the highest level of practice, 3.51-4.50 indicates frequent practice, 2.51-3.50 denotes intermediate practice, 1.51-2.50 suggests occasional practice and 1.00-1.50 reflects no practice.

RESULT AND DISCUSSION

Identify Causes of Loss in Cabbage Production

The data presented in Table 1 and Figure 2 illustrate that weather variability significantly impacts cabbage losses among farmers. This variability is evidenced by a practice level of 2.08, indicating only occasional use of climate-control instruments such as hygrometers,

temperature gauges, and rain gauges in their fields. This sporadic use suggests that farmers have limited capacity to mitigate weather-related issues affecting plant growth and crop quality. Moreover, the management of funding and funding sources achieves an intermediate practice level of 3.49. Additional challenges such as 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 packaging, harvest time, sprouts and seeds, and Transportation of products from the farm to the collecting and packing place are addressed more frequently. These areas achieve practice levels of 3.64, 3.86, 3.90, 3.93, 4.18, 4.20, 4.26, 4.28, 4.37, 4.38, 4.39, and 4.42, respectively.

During focus group discussions, farmers expressed that during abnormally high temperatures, they need to increase water irrigation to maintain optimal field temperatures. However, if temperatures become uncontrollable, excessive heat can adversely affect cabbage growth, resulting in stunted plants. Additionally, weather variability heightens the risk of plant diseases, which become harder to manage under fluctuating conditions. In some instances, farmers may be forced to destroy crops to prevent the spread of diseases.

Table 1
The level of farmers' practices affecting loss in cabbage production systems

Issues and Procedures	Level of Practice	Meaning of Practice Level	Std. Deviation
1. Weather variability	2.08	occasional practice	0.740
2. Funding and Funding source	3.49	Intermediate practice	0.913
3. Natural disasters	3.64	Frequent practice	0.759
4. Cultivation and maintenance	3.86	Frequent practice	0.635
5. Cleanliness and standards of the collecting and packing place	3.90	Frequent practice	0.598
6. Production plan	3.93	Frequent practice	1.009
7. Farmers' knowledge and skills	4.18	Frequent practice	0.781
8. Workers	4.20	Frequent practice	0.552
9. Diseases and pests	4.26	Frequent practice	0.611
10. Tools and harvesting method	4.28	Frequent practice	0.612
11. Cleaning and trimming of produce before packing	4.37	Frequent practice	0.865
12. Harvest Time	4.38	Frequent practice	0.916
13. Sprouts or Seeds	4.39	Frequent practice	0.714
14. Transportation of products from the farm to the collecting and packing place	4.42	Frequent practice	0.946

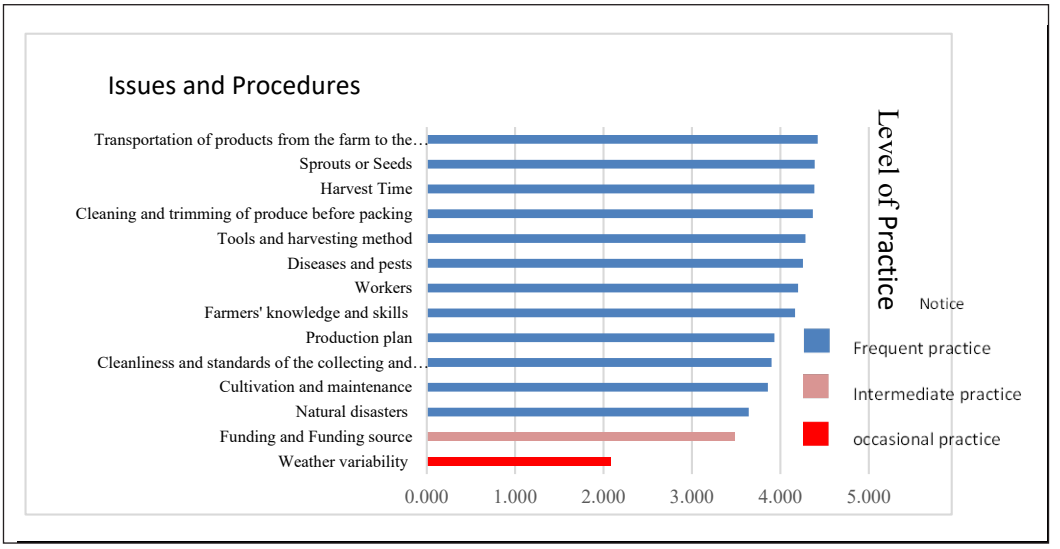

Figure 2. Identify causes of loss in the cabbage production system

The Losses of Cabbage in Terms of Both Quantity and Quality at the Farm Level

The assessment of losses in terms of mass at the farm level during the harvesting stage is presented in Table 2, which indicates that cabbage losses totalled 3,231.79 kilograms per rai, accounting for 66.58% of the yield. Figure 3 identifies the primary causes of these losses through visual inspection: 24% were due to unmarketable size, 23% to trimmed leaves, 13% to pest and disease damage, and 6% to stunted growth. Consequently, only 34% of the total harvested products were of good quality and suitable for sale.

The assessment of cabbage losses considers both economic and nutritional factors. According to the average yield production data presented in Table 3, which amounts to 4,854 kilograms per rai, the evaluation is based on the market price per kilogram, sourced from the Talaadthai market in August 2022, approximately 32.50 Baht per kilogram. Consequently, the economic loss per rai of cabbage is estimated at approximately 105,033 Baht (Talaadthai, n.d.).

Table 4 provides an assessment of nutrient losses per rai, based on the average yield outlined in Table 3, showing a loss of 3,231.79 kg per rai. The results further highlight significant losses of key nutrients, including energy, carbohydrates, potassium, phosphorus, calcium, sodium, and vitamin C. The estimated losses are 775,630.37 kcal/rai, 104,710.10 grams/rai for carbohydrates, 7,627.03 grams/rai for potassium, 1,163.45 grams/rai for phosphorus, 1,098.81 grams/rai for calcium, 807.95 grams/rai for sodium, and 614.04 grams/rai for vitamin C, respectively. These figures underscore the substantial nutrient losses that occur during cabbage production.

Table 2
Mass of cabbage losses at the farm level

Mass of losses	Quantity
Average yield production per rai	4,854 kg/rai
Total sample weight	202.80 kg
Total weight of losses	133.00 kg
Per cent of losses (100 × 133.00 kg)/ 202.80 kg	66.58%
Total weight of losses per rai	3,231.79 kg

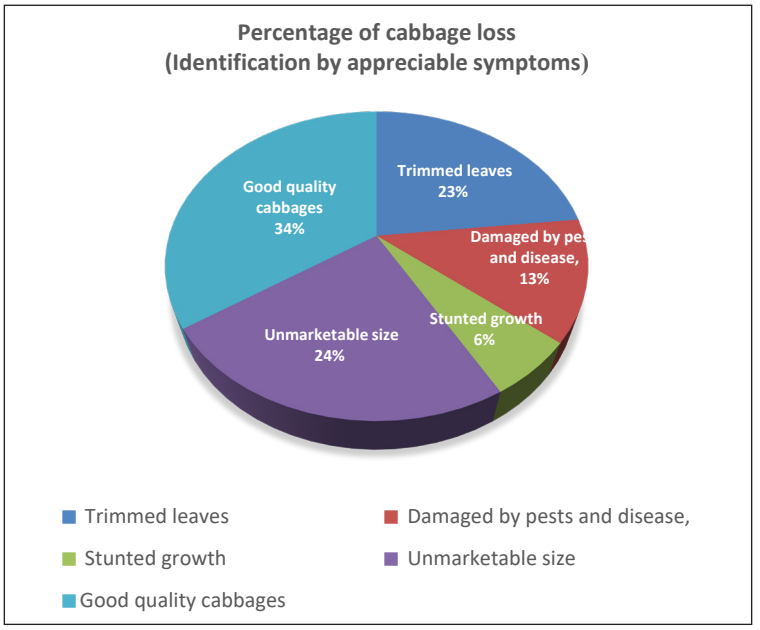

Figure 3. Percentage of cabbage loss, identification by appreciable symptoms

Table 3
Economics of cabbage losses

Economic Losses	Quantity
Average yield production per rai	4,854 kg/rai
The average market price per kilogram (Reference from Talaadthai market in August 2022)	32.50 Baht/kg
Total weight of losses per rai	3,231.79 kg
Economic losses (3,231.79 kg × 32.50 Baht/kg)	105,033 Baht/rai

Table 4
Nutrient of cabbage 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)	24 Kcal	775,630.37 Kcal
Carbohydrate, available	Calculated by difference: CHOAVLDF = 100 – (weight in grams [water + protein + fat + dietary fiber + ash] in 100 g food)	3.24 g	104,710.10 g
Potassium	AOAC method	236 mg	7,627.03 g
Phosphorus	AOAC method	36 mg	1,163.45 g
Calcium	AOAC method	34 mg	1,098.81 g
Sodium	AOAC method	25 mg	807.95 g
Vitamin C	AOAC - HPLC method	19 mg	614.04 g

Note. Total weight of losses: 3,231.79 kg/rai

Discussion

The data depicted in Fig. 2 indicate that weather variability is the primary factor contributing to cabbage losses at the farm level, largely due to the infrequent use of climate-control tools in the planting area. This variability significantly impacts farming practices, leading to heightened cabbage losses. Correspondingly, other researchers have identified weather variability as a principal cause of food losses across various agricultural sectors, including fruit and vegetable losses (Magalhães et al., 2022) and farm-level crop yield losses in German agriculture (Schmitt et al., 2022). This study aligns with other research examining postharvest management and its impact on the quantity and quality losses of leafy vegetables, revealing that these losses vary with both external and internal factors. External factors identified include temperature, humidity, atmospheric composition, light, gravity, and pests (Boonyakiat et al., 2012). Field data indicate the primary causes of loss, as visually identified: 24% due to unmarketable size, 23% due to trimmed leaves, 13% due to pest and disease damage, and 6% due to stunted growth. Consequently, only 34% of the total products were of good quality and ready for sale. Similarly, a study on postharvest losses of vegetables within the Royal Project Foundation demonstrated that the predominant causes of loss were underutilised parts of vegetables, insect damage, and mechanical injuries (Boonyakiat et al., 2012). Another study, Chompupoung (2017), conducted in the Royal Project Foundation's highland fields identified factors contributing to agricultural losses in three ways: first, losses stem from subpar-quality products, disease infections, insect infestations, weather fluctuations, natural disasters, and the prevalence of recessive species before harvest. The second phase centres on the harvesting process, where product damage

arises from suboptimal harvesting techniques and improper equipment use. Additionally, product deterioration results from untimely harvesting, limited knowledge, and the absence of post-harvest management technology. The final phase occurs post-harvest, during which products sustain bruising due to inadequate packaging methods, container handling, and inefficient transportation from the farm to the packing facility. Both quantitative and qualitative losses in cabbage may affect economic and nutritional value, as well as food safety. Despite awareness of food loss issues, many farmers are unable to quantify losses during production processes.

Within ASEAN countries, the study explored the significance of food loss concerning economic growth. The findings revealed that the Food Loss (FL) value as a percentage of GDP in Cambodia, Laos, Myanmar, and Vietnam (CLMV countries) exceeded that of Indonesia, Malaysia, the Philippines, and Thailand. Thus, it is crucial that economic development strategies extend beyond traditional GDP growth and prioritise sustainability. Nations should adopt inclusive economic growth objectives that address losses in both production and marketing processes. A promising strategy involves adopting a "circular economy for food." To mitigate agricultural product losses, governments should increase investments in research and development of post-harvest technologies and the improvement of logistics systems (Jaroensathapornkul, 2021).

The study investigating strategies employed by maize farmers in Delta State, Nigeria, to mitigate post-harvest losses yielded significant findings. This research examined the methods these farmers adopted to reduce losses. The results revealed that the primary factor contributing to post-harvest losses was a lack of awareness about modern storage facilities (Ovharhe, 2021). It was observed that post-harvest losses were most significant at the storage phase, exacerbated by inadequate extension services, infrequent visits, and the absence of governmental incentives for storage activities. One of the most effective strategies identified for minimising post-harvest losses was the use of storage bags. Numerous researchers have corroborated the efficacy of bags in storing beans, cereals, and legumes (Ikegwu et al., 2022; Uebersax et al., 2022). The study also highlighted significant constraints, including limited institutional support for post-harvest activities and the use of less efficient processing technologies, establishing a significant relationship between these factors. However, a major challenge in recovery efforts remains the variability and unpredictability of natural on-farm food losses. Future studies should concentrate on a critical analysis of the variability and unpredictability of on-farm cabbage loss.

CONCLUSION

This study found that weather variability significantly influences farming practices and is identified as the primary contributor to cabbage losses, with an observed practice level of 2.08. The quantified loss of cabbage per rai was substantial, at approximately 66.58%

(3,231.79 kilograms). Visual observations indicated that 24% of these losses were due to unmarketable sizes, 23% to trimmed leaves, 13% to pests and diseases, and 6% to stunted growth. Consequently, only 34% of the harvested cabbage met the criteria for good quality and market readiness. The associated economic loss was estimated at approximately 105,033 Baht per rai. Additionally, the study highlighted significant nutrient losses, quantifying them as 775,630.37 kcal of energy per rai, 104,710.10 grams of carbohydrates, 7,627.03 grams of potassium, 1,163.45 grams of phosphorus, 1,098.81 grams of calcium, 807.95 grams of sodium, and 614.04 grams of vitamin C. These findings emphasise the profound impact of cabbage losses on both economic and nutritional fronts, underscoring the urgency of addressing and mitigating them. Furthermore, the quality analysis showed that only a minority of the cabbage crop was high-quality and suitable for sale, underscoring the critical need for interventions to improve farming practices and reduce losses. The economic and nutritional losses documented in this research offer valuable insights that can inform the development of strategies to boost cabbage production efficiency and food security. Additionally, this study lays the foundation for raising farmers' awareness of production losses, which can inform targeted training initiatives to prevent and reduce food waste, thereby promoting more sustainable agricultural methods. These efforts contribute to sustainable cabbage cultivation, reduced food wastage, enhanced food security, and a lower environmental footprint, aligning with the global drive for environmental responsibility and sustainable resource management.

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