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Analysis of Food Prevention and Reduction in Cabbage Supply Chain: A Review

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Abstract: *This study examines food loss and waste (FLW) in the cabbage (Brassica oleracea / Brassica rapa) supply chain as a critical challenge to sustainable food systems. Cabbage is highly susceptible to losses due to intensive trimming practices, mechanical damage, non-protective packaging, and the absence of cold chain infrastructure, particularly in modern and online market channels. This study aims to identify FLW hotspots along the cabbage value chain and evaluate prevention and valorization strategies within a circular economy framework. A narrative review with a semi-systematic approach was employed to synthesize peer-reviewed literature, including studies applying the FAO Food Loss Analysis (FLA) methodology. The analysis focuses on identifying key drivers, impacts, and mitigation strategies across supply chain stages. The results indicate cumulative losses ranging from 18–51%, primarily driven by repeated handling, strict visual quality standards, and inadequate logistics systems. Preventive interventions such as Good Handling Practices (GHP), reusable plastic crates, and improved early-stage transport systems show strong potential for reducing losses. In addition, cabbage residues can be valorized into functional ingredients, animal feed, bioenergy, and bio-based materials. Overall, integrating prevention and valorization provides a practical pathway to reduce FLW and enhance sustainability in horticultural supply chains.*

Keywords: *Circular Economy, Food Loss, Food Waste, Valorization*

Introduction

The global food system currently faces significant challenges in meeting the nutritional needs of the world's population without exceeding the planet's capacity, with food loss and waste emerging as major obstacles. It is estimated that approximately one-third of all food produced for human consumption, or approximately 1.3 billion tons, is lost or wasted annually (Ortiz-Gonzalo et al., 2021). This problem has broad systemic impacts, from threatening food security to causing massive waste of natural resources, including the wasteful use of 20% of agricultural land, 70% of freshwater extraction, and 32% of global energy consumption (Ishangulyyev et al., 2019). Environmentally, the decomposition of food waste in landfills contributes significantly to greenhouse gas emissions, particularly methane, while economically, global losses are estimated to exceed USD $1 trillion per year, placing a heavy burden on farmers, supply chains, and consumers (Ortiz-Gonzalo et al., 2021). Within the fresh produce category, horticultural vegetables have a much higher loss rate than dry food products, and cabbage (*Brassica oleracea or Brassica rapa*) is one of the commodities with a very prominent level of food loss and food waste (FLW) (Bisht & Singh, 2024). Cabbage is mass-produced and widely consumed in a variety of processed forms, but it is highly susceptible to waste due to the intensive practice of trimming outer leaves to meet retail aesthetic standards (Ortiz-Gonzalo et al., 2021). A head of cabbage can lose between 44% and 66% of its wet weight before reaching the consumer due to this cleaning process (Ortiz-Gonzalo et al., 2021). The biological characteristics of cabbage, such as high water content (around 90%) and fast respiration rate, make it very sensitive to temperature and humidity, thus accelerating the post-harvest wilting and rotting process (Bisht & Singh, 2024). Mechanical damage from rough handling and appearance issues such as discoloration often lead to market rejection, even though the inside remains nutritionally intact. These losses occur at various points along the food chain, from production and harvest in the field, through post-harvest handling, transportation, and retail and household consumption (Munhuweyi et al., 2016). It is important to distinguish between food loss that occurs at the production stage through distribution before retail, and food waste that occurs at the retail and consumer levels (Ortiz-Gonzalo et al., 2021). Strategies to address this problem must prioritize prevention at the source in accordance with the waste management hierarchy, followed by efforts to valorize or increase the use value of residues into new products within a circular economy framework (Ortiz-Gonzalo et al., 2021).

Although research on food waste has increased dramatically in the last decade, there is a significant research gap where literature focusing specifically on cabbage commodities is still limited compared to studies on household waste in general (Spang et al., 2019). Many current solutions are still limited to end-of-life management such as composting and high retail visual standards often force the disposal of edible products, creating social and economic problems that need to be evaluated (Gage et al., 2024). The purpose of this literature review is to critically examine the literature related to FLW management in cabbage, focusing on identifying hotspots along the supply chain. To achieve this objective, the study addresses the following research questions: Where are the key drivers behind food loss and waste at each stage of the cabbage supply chain? What prevention strategies are most effective in reducing losses at different stages of the supply chain? How can cabbage waste be valorized into value-added products within a circular economy framework?

This article will analyze various prevention strategies through technological interventions and behavioral change, and explore opportunities for the valorization of cabbage waste, such as outer leaves and stems, into value-added products that support the sustainability of the global food system. Despite these contributions, existing studies remain fragmented and rarely integrate supply chain hotspot identification, prevention strategies, and waste valorization within a single framework. This study addresses this gap by providing a commodity-specific synthesis of cabbage-related FLW. The novelty of this study lies in its integrative and commodity-specific approach, which not only connects supply chain hotspot identification, prevention strategies, and waste valorization, but also links these dimensions to practical and evidence-based intervention points across the cabbage supply chain.

Research Method

This study employed a narrative review method with a semi-systematic approach to synthesize existing knowledge on food loss and waste (FLW) in the cabbage supply chain. A narrative review allows flexibility in integrating findings from diverse sources and perspectives, while still maintaining a structured search and analysis process. The data sources for this study consisted of peer-reviewed journal articles and review papers obtained from major academic databases, such as Google Scholar, Scopus, and ScienceDirect published between 2015 and 2025 using combinations of keywords such as "food loss", "food waste", "cabbage supply chain", "post-harvest handling", and "sustainable agriculture". Boolean operators (AND, OR) were used to refine the search result. The inclusion criteria for literature selection were as follows: journal publication within the last 10 years (2015-2025), focused on food loss and waste in horticultural commodities, particularly cabbage or similar perishable vegetables, discussed supply chain stages, post-harvest handling, or waste management strategies, and relevant to the Indonesian context or developing countries with similar agricultural systems. The data were analyzed using a thematic analysis approach to identify recurring patterns related to the causes, impacts, and mitigation strategies of FLW in cabbage supply chains. Thematic synthesis enables the integration of findings across multiple studies while maintaining a clear link between original data and derived concepts. The analysis process involved data extraction from selected studies, coding of key findings, and grouping codes into broader themes to generate an integrated understanding of FLW management.

Result and Discussion

Food Loss and Food Waste in Cabbage Along the Value Chain

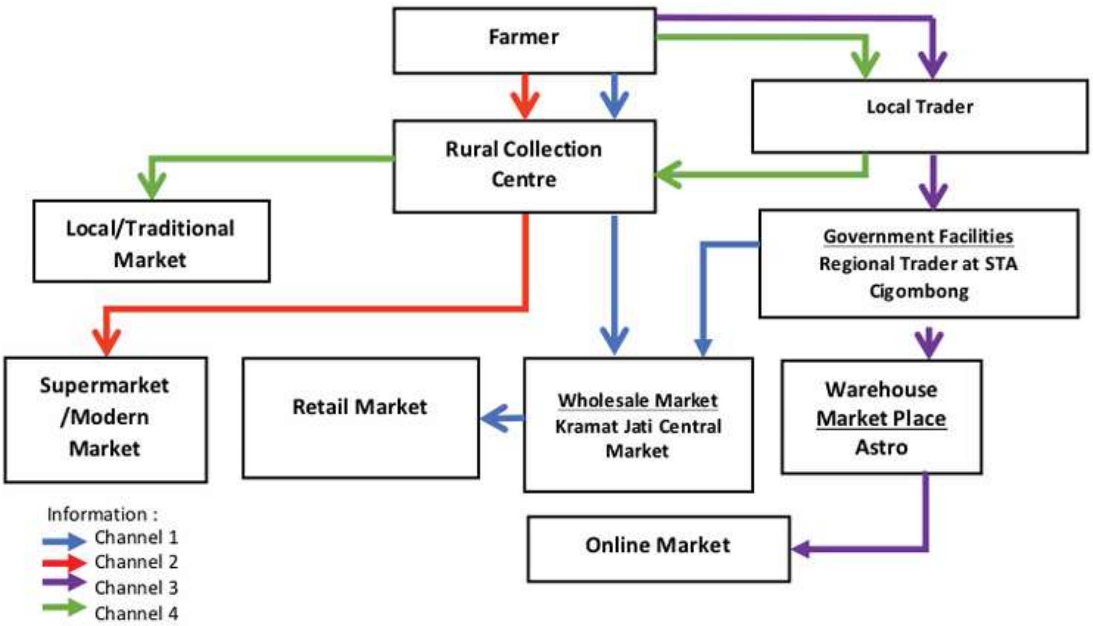


Figure 1. Marketing system and value chain map of cabbage. Source: (Eriyatno et al., 2024)

An analysis of the cabbage value chain in Cianjur based on product flow tracing, supply chain actor interviews, and loss point measurements shows that food loss and food waste occur simultaneously and cumulatively along four distribution channels with a very high loss range of around 18–51% and the largest on the route to modern markets and online platforms (Eriyatno et al., 2024). These findings stem from load tracking at the farmer level, village traders, RCC, STA Cigombong, and the final market, which is then mapped into the cabbage marketing system in Figure 1. The cabbage marketing structure forms a branched network centered on the Rural Collection Center and STA Cigombong before flowing to the Cianjur traditional market, Kramat Jati wholesale market, modern supermarkets, and the Astro online platform. Upstream in the supply chain, farmers in Pacet, Cugenang, and Sukasari generally rent around 0.2 hectares of land from PTPN and have production pouches to ensure market supply, with a clear gender division of labor: women plant seeds while men plow, spray, harvest, and lift the harvest. After harvesting from morning to evening, the cabbage moves to village traders who perform initial peeling, weighing, and packaging using motorcycles or pickup trucks to the RCC. At RCCs such as Mujagi or the Sukaluyu farmers' association, the cabbage is further peeled according to target market demand before being partially shipped to STA Cigombong, which is under the auspices of the Ministry of Agriculture and functions as a regional collection center with transaction rooms, packing houses, and transportation facilities. From the STA, the cabbage flows to Kramat Jati or to Astro's warehouse in Jakarta, where it is cleaned, re-peeled, and individually packaged for online sales. Within this overall structure, food waste primarily arises from cleaning, trimming, peeling, and sorting practices to meet market visual standards, such as removing roots and outer leaves at the RCC or stripping the outer layers of cabbage heads. Food loss is primarily driven by repeated transportation, unprotected packaging such as plastic sacks or netting, and the absence of a cold chain, which leads to mechanical damage and spoilage.

Following the channel flow shown in Figure 1, each channel generates a different combination of loss and waste. In Channel 1, farmers send whole cabbages to the RCC and then to the Kramat Jati wholesale market. Waste occurs at the RCC when roots and outer leaves are removed to meet wholesale standards, while loss occurs during overnight open-truck transportation, which leads to wilting and bruising before arrival at the market. In Channel 2, waste intensity increases at the RCC due to more stringent peeling, sorting, and cleaning processes for urban markets. Despite being packaged in plastic and small boxcars, long-distance shipping without a cold chain still results in losses in the form of dehydration and discoloration, potentially triggering re-trimming at the destination. In Channel 3, waste occurs in layers, from initial trimming in the field, re-cleaning at the RCC, to highly stringent sorting by Astro at the Cigombong STA for online markets. Repeated multi-stage handling without refrigeration increases mechanical damage. At Channel 4, the risk of loss is highest from the start because the cabbage is transported by motorbike using a waring (a type of coarse, open-mesh polyethylene bag commonly used in Indonesia for agricultural product packaging) through steep terrain and dirt roads that cause repeated impacts and pressure before arriving at the village traders. At this stage, the coarse mesh offers minimal protection against bruising and compression damage. Upon arrival, individual peeling and plastic packaging are carried out, which again generates waste, even though the product is destined for traditional markets with lower visual standards.

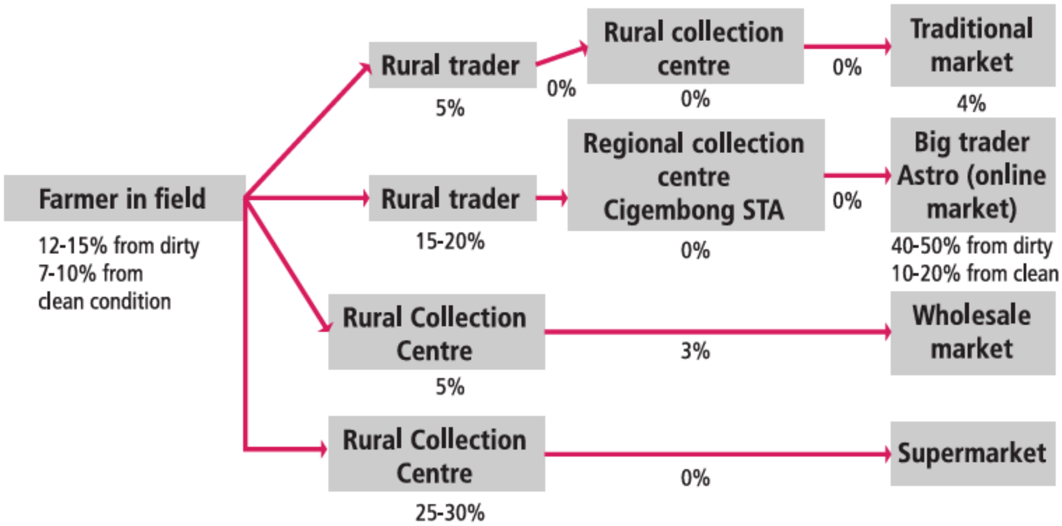


Figure 2. FLW points in the cabbage supply chain. Source: (Eriyatno et al., 2024)

Figure 2 maps the distribution of losses at each stage and shows that FLW is greatest in the early stages of the supply chain and on the path to modern and online markets. At the farm level, losses reach 12–15% of the gross condition and 7–10% of the net condition, reflecting the impact of harvesting techniques, knife quality, harvest time, and simple packaging before the product enters the RCC. An additional loss of less than 5% occurs during motorbike transportation from the field to village traders, with 2.67% lost during loading. In RCC Channel 1, peeling results in approximately 5% loss, and transactions at Kramat Jati reduce 3% weight to compensate for the damage, resulting in cumulative losses from field to wholesale market in the range of 18–27%. In Channel 2, peeling for modern markets results in 25–30% losses in the RCC, with supermarket rejections being less than 5%, resulting in cumulative losses from field to supermarket in the range of 34–42%. In Channel 3, the online market experienced the highest losses due to peeling occurring in the field, by small and large traders, and repeatedly in the Astro warehouse, resulting in losses of 40–50% for dirty cabbage and 10–20% for clean cabbage for a cumulative total of 43–51% from the field to the online warehouse. In Channel 4, the use of 22–25 kilogram transparent plastic sacks or 30–50 kilogram netting resulted in approximately 4% losses in the local market, bringing the cumulative total from the field to the Cianjur traditional market to around 25–34%. Additional losses at harvest reached 7–15% due to late harvesting, delayed pesticide application, or harvesting when wet, which accelerates spoilage. Overall, this percentage pattern confirms that the FLW level of cabbage is not primarily determined by distribution distance but by market quality standards, repeated peeling practices, and the quality of logistics and handling infrastructure in each channel. From a practical perspective, these findings indicate that interventions should prioritize early-stage handling improvements, such as farmer training programs, improved packaging practices, and the adoption of simple transport innovations, which can be implemented through government extension programs, RRC-managed training schemes, or formal partnership between farmers, trades, and retail actors.

Food Loss Prevention Strategy for Cabbage Commodities

This discussion draws on FAO field-based research and related literature to examine food loss prevention strategies for cabbage supply chains in Indonesia, which were implemented in Cugenang, Cianjur Regency (Eriyatno et al., 2024). The cabbage supply chain structure is centered on the *R*ural Collection Centre (RRC) and the Sub Terminal Agribisnis (STA) forming a multi-tiered distribution system characterized by high handling frequency and non-thermal logistics conditions. Food loss in cabbage is primarily driven by mechanical stress, dehydration, and physiological quality degradation resulting from repeated handling, and non-protective packaging, and transportation without adequate support systems. This pattern is consistent with postharvest studies showing that mechanical damage significantly accelerates quality deterioration in leafy vegetables through increased water loss, respiration rate, and microbial infiltration (Liu et al., 2025). Therefore, prevention strategies for cabbage are conceptually based on minimizing sources of physical and physiological stress from harvest through early distribution stages.

Good Handling Practices (GHP) constitute the primary foundation for preventing food loss and food waste in cabbage. Non-uniform harvesting practices, rough stem cutting, and multiple layers of sorting and peeling have been shown to increase damage to epidermal and mesophyll tissues, which subsequently accelerates respiration and transpiration processes. Post harvest physiology studies demonstrate micro-injuries in leaf tissues activate hydrolytic enzymes such as chlorophyllase and pheophytinase, thereby accelerating chlorophyll degradation, reducing visual quality, and shortening shelf life (Yang et al., 2024). The FAO emphasizes that improving GHP through harvest and early handling training can significantly reduce losses before products enter RRC (Eriyatno et al., 2024). Strategies for reducing postharvest losses in horticultural commodities highlight that proper GHP, including shorting, grading, storage, and handling is crucial in minimizing postharvest losses, and that implementing standardized procedures results in lower losses compared to poor practices without adequate training (Ira Mulyawanti, 2024). In practice, this implies that capacity-building programs for farmers and local traders, such as training on proper cutting techniques, sorting standards, and postharvest handling protocols, supported by government or supply chain actors, can serve as cost-effective interventions to reduce losses at the source.

Table 1. Budget calculation for reducing cabbage losses using plastic crates

	Item	Value	Unit	Calculation
a	Product quantity (3 harvests)/year, 50% cabbage	7800	tonnes/year	Production of Mujagi Farm
b	Product value	129	USD per	

			tonne	
c	Loss rate	25	percent	Quantitative & qualitative
d	Anticipated loss reduction	40	percent	
e	Cost of Intervention	48387	USD	Training kit, audio visual kits, content creation
f	Depreciation	5	Year	Average life span of equipment
g	Yearly cost of investment	9677	USD	e/f
h	Yearly cost of operation	19355	USD	USD 1613/month
i	Total yearly cost of solution	29032	USD	g+h
j	Client cost per tonnes product	3,72	USD//tonnes	i/a
k	Food loss	1950	tonnes/year	c*a
l	Economic loss	251613	USD/year	k*b
m	Loss reduction	780	tonnes/year	k*d
n	Loss reduction savings	100645	USD/year	m*b
o	Total client loss	29032	USD/year	a*j=i
p	**Profitability of solution**	**70194**	**USD/year**	**n-o**

Source: Eriyatno et al. 2024

Cost-benefit analysis indicates that the GHP capacity-building program has high economic feasibility, with an annual cost approximately USD 29,032 and potential loss reduction of up to 780 tons per year, generating estimated economic savings of around USD 100,645 annually. Thus, GHP functions not only as a technical practice but also as a structural instrument that reduces the formation of downstream food waste caused by repeated trimming required to meet market visual standards.

Packaging is a determining factor in controlling mechanical damage to cabbage during transportation. The use of plastic sacks and mesh bags leads to uneven stacking pressure, friction between cabbage heads, and structural deformation of outer leaves.

Mechanical damage, which contributes 6-24% of quality deterioration in fruits and vegetables, often arises from compression, impact and vibration when packaging is non-protective (Yang et al., 2024). In contrast, the use of ventilated reusable plastic crates can reduce mechanical damage and better preserve the physical quality of cabbage. Experimental postharvest studies demonstrate that ventilated and rigid packaging structures, such as crates, improve air circulation and reduce mechanical pressure on horticultural products, thereby minimizing water loss and slowing quality degradation during handling and distribution (Cao et al., 2020; Wheeler et al., 2015).

Table 2. Budget calculation for reducing cabbage losses using plastic crates

	Item	Value	Unit	Calculation
a	Product quantity (3 harvests)/year, 50% cabbage	7800	tonnes/year	
b	Product value	129	USD per tonne	
c	Loss rate	10	percent	Quantitative & qualitative
d	Anticipated loss reduction	80	percent	
e	Cost of Intervention	12903	USD	1000 crates
f	Depreciation	5	Year	Average life span of equipment
g	Yearly cost of investment	2581	USD	e/f
h	Yearly cost of operation	7742	USD	USD 64516/month
i	Total yearly cost of solution	10323	USD	g+h
j	Client cost per tonnes product	1,32	USD//tonnes	i/a
k	Food loss	780	tonnes/year	c*a
l	Economic loss	100645	USD/year	k*b
m	Loss reduction	624	tonnes/year	k*d
n	Loss reduction savings	80516	USD/year	m*b
o	Total client loss	10323	USD/year	a*j=i

p	**Profitability of solution**	**70194**	**USD/year**	**n-o**

Source: (Eriyatno et al., 2024)

FAO recommends implementing a crates rental system through the Rural Collection Centre (RRC) and Sub Terminal Agribusiness (STA) to improve farmer's access to protective packaging, considering that the use of plastic sacks can result in losses of up to approximately ±10% (Eriyatno et al., 2024). Cost-benefit analysis shows that this intervention, with an annual cost around USD 10,323 can reduce losses by up to 624 tons per year and generate net benefits of approximately USD 70,194 annually. The shared crate system facilitated by STA and RRC expands demands farmer's access to protective packaging without increasing individual investment burdens, while simultaneously strengthening collective logistics efficiency. Within the prevention framework, packaging functions not merely as a physical container, but as a relatively low-cost food loss risk mitigation tool with systemic impact (Eriyatno et al., 2024). This suggests that establishing a shared crate rental system through RRC or STA can be implemented as a scalable solution to improve packaging practices without imposing high investment costs on individual farmers, particularly when managed at RRC or STA level to ensure equitable access and reduce individual investment barriers.

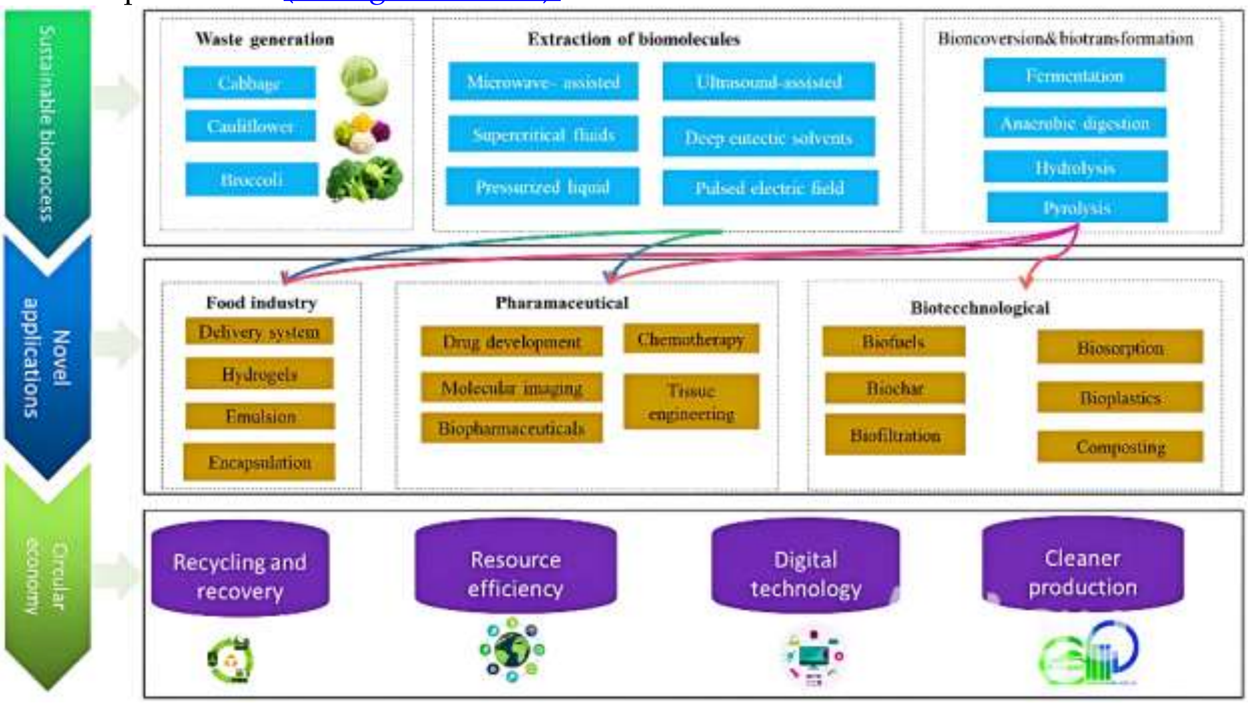
Initial transportation from the field to collection points represents a critical stage of cabbage food loss, particularly in hilly areas. Repeated manual handling increases the frequency of impacts and compression, thereby elevating the risk of damage before products enter the formal distribution system. Early-stage transport innovation provides strong evidence of a context-based prevention approach. Innovations such as trolley cableway systems directly reduce the number of handling cycles and transportation time, thereby minimizing the accumulation of mechanical stress on the product. Quality deterioration develops along the supply chain due to factors such as early handling, transport conditions, and logistical infrastructure (Al-Dairi et al., 2022). Suboptimal conditions at the initial stage lead to mass loss and quality decline, which subsequently contribute to further deterioration in later stages of the supply chain, demonstrating the cumulative nature of postharvest losses in horticultural products (Bisht & Singh, 2024). The implementation of trolley cableways system in hilly areas with limited road access, such as in Cugenang, Cianjur Regency has become a solution to reduce postharvest losses during early distribution. A similar approach is reflected in the "Sasak Apung Padjadjaran" developed by Universitas Padjadjaran in Suntejaya Village, Lembang. Prior to its implementation, farmers manually transported cabbage for approximately 500 meters along uphill dirt paths, increasing labor cost approximately ±USD 0,03/kg, prolonging distribution time, and elevating the risk of mechanical damage due to repeated handling (Eriyatno et al., 2024). After implementation, the trolley system is capable of transporting up to 500 kg of harvest within 3,5 minutes over a 300 meter distance, with electricity operating costs of around USD 0,67 for five days of use. The relatively low service fees, USD 0,0064/kg for vegetable distribution, USD 0,0064/kg for manure transport, and USD 0,13 per worker, demonstrate significant economic efficiency compared to conventional methods.

Valorization of Cabbage Waste

One of the factors contributing to the underutilization of cabbage is the failure to use the plant in its entirety. Whole plant utilization can unlock available resources and improve efficiency and sustainability within the supply chain (Spang et al., 2019). Food waste valorization transforms unavoidable fractions and byproducts into value added products. From an economic perspective, valorization creates new revenue streams from low-cost biomass and reduces waste management costs. As a complement to food loss and waste prevention strategies, valorization enables the sustainable utilization of unavoidable food waste within the supply chain (Gage et al., 2024). In the cabbage processing and distribution, residual components are typically found in the outer leaves, stems, and trimming residues. These fractions contain bioactive compounds and nutrients that support diverse valorization pathways. Vegetable residues are rich in carbohydrates, dietary fiber, and valuable polysaccharides that can serve as substrates for fermentation and animal feed (Capanoglu et al., 2022). Broader analyses of vegetable waste also reveal the presence of bioactive proteins and phytochemicals such as glucosinolates, flavonoids, anthocyanins, carotenoids, and related antioxidant compounds, enhancing their functional or high value application beyond simple disposal (Tsegay et al., 2024).

Due to the characteristics of cabbage residues, several technological approaches can be applied. Among these, fermentation and anaerobic digestion are particularly relevant due to the high moisture content of cabbage waste. These technologies enable conversion into biofuels, bioplastics, biochar, and nutrient rich digestate. Such methods not only maximize whole plant utilization but also support the development of functional food ingredients (Shinali et al., 2024). Numerous scientific reviews indicate that fruit and vegetable waste including leaves, stems, peels, pulp, and other byproducts can be effectively processed through these pathways. Vegetable waste is rich in phytochemicals (polyphenols, carotenoids, anthocyanins, and dietary fiber), which can be efficiently recovered using green extraction and advanced techniques to produce natural colorants, antioxidants, nutraceutical ingredients and functional food components (Ramzan et al., 2025). These compounds contribute to improved food quality and offer potential health benefits, representing valuable secondary revenue streams and supporting related industries such as dietary supplements. Microbial fermentation is widely reported as an effective method for converting vegetable waste into value added products, including organic acids, probiotic rich substrates, and fermented materials with enhanced bioavailability (Marcelli et al., 2025). Fermentation also reduces antinutritional factors and stabilizes waste, making it suitable for further applications in food, feed, or raw material production. In real-world applications, these valorization pathways can be implemented through small-scale agro-industries or partnerships with local processing units, such as community-based fermentation units, animal feed production, or small scale biogas systems integrated at the farm or RRC level, enabling farmers and supply chain actors to convert waste into additional income streams.

Cabbage, as a high water content vegetable, is well suited for anaerobic digestion, producing biogas (methane or hydrogen) while reducing organic load. In more advanced biorefinery concepts, intermediate products of digestion such as volatile fatty acids can serve as chemical precursors while the remaining digestate retains nutrients (nitrogen, phosphorus, potassium) suitable for reuse in agriculture as fertilizer or soil amendments (Hossain et al., 2025). Structural polysaccharides such as cellulose, hemicellulose, and pectin present in vegetable waste can also be utilized as functional fibers in food formulations or processed into bio-based materials, including biodegradable composites and biochar. Biochar production offers additional environmental benefits through soil improvement and carbon sequestration (Zhang et al., 2024).



Gambar 3. Visual illustration of the byproduct/waste valorization of cruciferous plants. Source : (Shinali et al., 2024)

Valorization supports circular economy principles by shifting food waste management from disposal toward resource recovery. By converting unavoidable vegetable losses into functional ingredients, bioenergy, fertilizers, or bio-based materials, valorizations extend the useful life of biomass and reduces dependence on virgin resources (Zhang et al., 2024). The suitability of each pathway is largely determined by the physical and chemical characteristics of the waste stream, as well as the technological and economic feasibility. When implemented strategically, waste utilization serves not merely as a waste treatment option, but as an integral component of a circular food system strengthening sustainability goals while complementing food loss and waste prevention efforts.

Conclusion

This study concluded that the cabbage supply chain has a very high loss rate, ranging from 18% to 51%, with the main critical points (hotspots) located in the early production stage and modern distribution channels due to retail aesthetic standards that trigger repeated peeling and rough logistics handling. Interventions through preventive strategies such as the implementation of Good Handling Practices (GHP), the use of ventilated plastic crates, and trolley cableway technology have proven to be economically feasible because they can reduce mechanical stress and significantly extend the shelf life of commodities. Furthermore, the utilization of cabbage residues through the valorization pathway into functional food ingredients, feed, and bioenergy is a crucial solution in integrating circular economy principles into the food system. As an application recommendation, stakeholders need to strengthen the role of regional collection centers in facilitating collective logistics infrastructure and educating the market to adopt more inclusive quality standards for "imperfect" products to reduce the waste of food that is actually still nutritious. From a policy perspective, these finding highlight the need for coordinated interventions, including improved postharvest infrastructure, standardized handling practices, and broader acceptance of “imperfect” product to reduce unnecessary food waste. Future research should focus on quantitative and commodity-specific assessments across different regions, as well as integrating economic, behavioral, and technological approaches to evaluate the long-term effectiveness of FLW reduction strategies. Overall, this study demonstrates that integrating prevention and valorization within a commodity-specific framework provides a practical pathway to significantly reduce FLW while enhancing economic and environmental sustainability.

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