FOOD LOSS ANALYSIS

Harvest to Retail for Agriculture Value Chains

October, 2025

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List of Acronyms

VC	Agricultural Value Chain
AMS	The Association of Southeast Asian Nations Member States
FL	Food Loss
FW	Food Waste
GI	Geographical Indication
GHG	Greenhouse Gas
MSMEs	Micro, Small, and Medium Enterprises
MC	Moisture Content
RCN	Raw Cashew Nut
CNS	Cashew Nutshell
CNSL	Cashew Nutshell Liquid

Abstract

Cambodia's agricultural sector, contributing 20% to the nation's GDP and employing 31% of the population, is central to economic growth, poverty reduction, and food security, but also a major source of greenhouse gas emissions and highly vulnerable to climate change. Under the EU-funded *Accelerating Sustainability in Cambodia's Agri-Food System* (ACSA) project, this study assesses food loss and waste (FLW) across six major agricultural value chains in five provinces of Cambodia—pepper, cashew, cassava, coconut, corn, and sugarcane—focusing on the scale of losses, current valorisation practices, and opportunities for circular economy interventions.

Field data collection and secondary analysis revealed that while on-farm losses vary, significant proportions of crop biomass remain underutilised or discarded across all chains. In cashew production, up to 90% of the fruit biomass (cashew apple) is typically left to rot or minimally used as fodder, while in coconut distribution, as much as 83% of harvested biomass risks being wasted without valorisation. These patterns highlight substantial untapped opportunities to improve resource efficiency, reduce emissions, and enhance rural livelihoods.

To address these gaps, the study identifies feasible valorisation strategies, drawing on both local practices and international experience. Opportunities include animal feed, compost, bioenergy, and higher-value product development, but three stand out as pilot-ready: processing cashew apples into sugar, transforming coconut by-products into charcoal, and processing cashew nutshell for CNSL. These recommendations are guided by technical feasibility, market demand, and alignment with Cambodia's circular economy and climate resilience agendas. Together, they demonstrate how targeted interventions can reduce agricultural waste, add value to underutilised by-products, and support sustainable development pathways in Cambodia's agri-food system in line with ACSA objectives.

A. Context of the Study

About ASCA

PIN, in partnership with Husk Ventures (Cambodia) Co., Ltd. and the Farmer and Nature Network (FNN), is leading the three-year Accelerating Sustainability in Cambodia's Agri-Food System (ASCA) project (2025–2027), funded by the European Union through the SWITCH-Asia programme and supported by Ministry of Agriculture Forestry and Fishery (MAFF). The project aims to drive the transition of Cambodia's agri-food system towards sustainability by promoting the use of carbon-based fertilizers, improving resource efficiency, and fostering economic growth in rural areas.

The key objectives are to:

- Strengthen decarbonisation in agriculture by promoting carbon-based fertilizers, advancing Green Agriculture Technology, and reducing food loss in rural MSMEs.
- Raise awareness of sustainable practices, facilitate policy discussions, and build alliances to promote Green Agriculture Technology solutions.

As part of efforts to understand and scale sustainable practices, PIN has commissioned a study to analyse, map, and quantify food loss occurring between harvest and retail.

The study aims to formulate a valorisation strategy and recommend the most promising initiatives for piloting. It will focus on:

1. Losses occurring at wet markets and agricultural distribution centres.
2. By-products or residual waste generated through selected value chains—cashew, cassava, corn/maize, coconut, pepper, and sugarcane—in the provinces of Kampot, Battambang, Kampong Speu, Kampong Thom, and Phnom Penh.

B. Approach and Methodology

Methodology

The assessment employed a mixed-methods approach, combining field data collection from 93 farmers' cooperatives, collectors, traders/aggregators, wholesalers, processors, and retailers across the target provinces—46% of whom were women. Multiple tools and references were applied, including structured questionnaires; a review of government policies; literature on regional valorisation practices and academic studies; validation through cross-referencing with GIZ's Rapid Loss Analysis Tools (RLAT); value chain analysis reports (2024–2025); and consultations with Provincial Departments of Agriculture, Forestry, and Fisheries (PDAFF). Value chain mapping was used to identify stakeholders and pinpoint loss hotspots from harvest to retail. Quantitative analysis estimated food loss percentages at each stage, employing triangulation methods to validate the data. The study areas were selected based on the production potential of each crop: Battambang (cassava and corn), Kampong Thom (cashew nut), Kampong Speu (sugarcane), Kampot (pepper and coconut), and Phnom Penh (sugarcane and coconut), as shown in Figure 1.

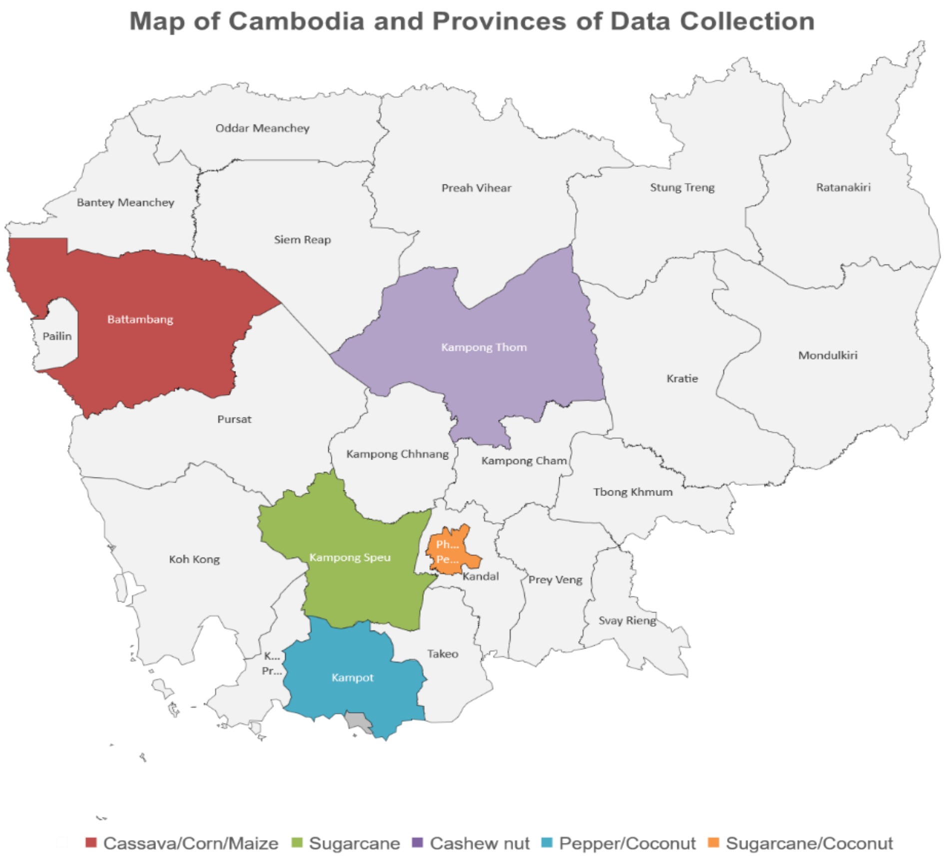

Figure 1: Map of Cambodia and province for data collection.

C. Background and Introduction

1. About Agriculture, Food Loss, Emissions and Food Security

This section tackles the topic of Agriculture, Food Security, Emissions and Food Loss from a global perspective to a more local one, focusing on ASEAN countries and Cambodia. According to the FAO, food loss refers to any food that is discarded or disposed of along the food supply chain from harvest to retail[1]. Food loss can be quantitative, a loss of weight or a loss of physical product for example, or qualitative with a depletion of the food nutrients or specific content therefore decreasing its value.

2. Agriculture, Food Loss and Emissions

The agriculture sector has been the bedrock of economic growth and global integration for most ASEAN countries. The sector contributes approximately 11% of the ASEAN's region's GDP; in Cambodia, it contributes about 20% of the country's GDP[2] employing about 31% of its total population[3] in 2019.

Cambodia's population is expected to increase from 17.5 million in 2025 to 22 million in 2050[4] which underscores the important role of the agriculture sector to ensure food security, livelihood and economic stability.

Cambodia is among the most vulnerable to climate change ranking 17th among the 20 most vulnerable countries according to the Climate Risk Index 2025. The sector most at risk to climate change is agriculture. Against the backdrop of limited infrastructure, transport and storage facilities, food loss in the agriculture value chain compounds threats to food security. **Food security** is still an important issue in Cambodia as 16% of households cannot afford a nutritious diet and 22% of children are stunted (development is impaired due to malnutrition)[5]. Acknowledging these threats there is urgent need for Cambodia's agricultural sector to become **more productive, resilient and sustainable**.

According to the NDC 2.0 stock take conducted by Sevea in 2024, agriculture is one of the main sources of greenhouse gas (GHG) emissions and the most vulnerable to the impact of climate change. The sector will contribute to 27% of total emissions by 2030 under business as usual (BAU) scenario. These emissions are due to mechanization of agricultural practices utilizing fossil fuels, the use of chemical inputs, livestock production, land-use change caused by deforestation, biomass fires, peatland degradation processes, food manufacturing [6]and rice production which currently contributes to 11% of global methane emissions. [7] The Royal Government of Cambodia (RGC) has implemented several measures to reduce emissions from the sector such as promoting the use of conservation agriculture practices.

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[1] https://www.fao.org/platform-food-loss-waste/food-loss/introduction/en

[2] https://www.frontiersin.org/journals/sustainable-food-systems/articles/10.3389/fsufs.2023.1260619/full

[3] https://mekonginstitute.org/improving-postharvest-practices-to-reduce-food-loss-2/#:~:text=Postharvest%20losses%20typically%20range%20from,in%20developing%20countries%2C%20including%20Cambodia.

[4] https://www.nis.gov.kh/nis/Census2019/Population%20Projection.pdf

[5] https://www.wfp.org/countries/cambodia

[6] https://www.fao.org/statistics/highlights-archive/highlights-detail/greenhouse-gas-emissions-from-agrifood-systems.-global--regional-and-country-trends--2000-2022/en

[7] https://www.fao.org/4/y4252e/y4252e.pdf

3. Food Loss and Food Systems Resilience

The main food groups contributing to nutrient and food waste, or loss are cereals and pulses, fruits and vegetables, meat and animal products, roots, tubers, and oil crops (Esra Capanoglu, 2022). Postharvest losses occur throughout the commodity value chain and vary by crop and region. A **key constraint to effective loss reduction** is the **lack of empirical data on where, how much, and why losses occur** (Hodges et al., 2011; Prusky, 2011; Affognon et al., 2015).

Losses at later stages of the value chain such as during marketing or distribution usually impose higher economic costs than early-stage losses due to the added value along the chain. Therefore, targeted interventions and valorisation based on where and when losses occur can yield greater economic and environmental benefits.[8] The HLPE (High Level Panel of Experts on Food Security and Nutrition) 2014 report on "Food Losses and Waste in the Context of Sustainable Food Systems", recommends a food-use-not-loss-or-waste hierarchy (Figure 2).

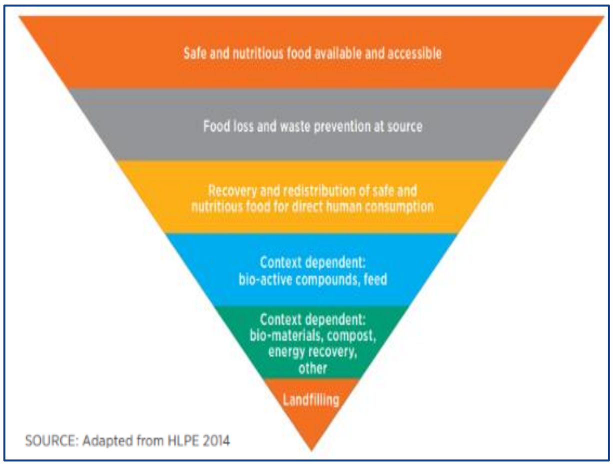

Figure 2: Food-use-not-loss-or-waste hierarchy.

This hierarchy prioritizes strategies to prevent food loss and waste, emphasizing the importance of using food for its intended purpose (human consumption) before considering other options. **The hierarchy places the most desirable actions (like preventing food loss at the source) at the top** and the least desirable (like disposal) at the bottom.

4. Food Loss and Valorisation

Agrifood waste (loss) has significant negative consequences, impacting the environment, food security, and the economy. It contributes to GHG emissions, inefficient use of valuable resources, decrease in farm income, and reduction in food availability and stability.

In developing countries like Cambodia and most ASEAN member states (AMS) food loss (FL) mostly occurs at the post-harvest and processing stages of the value chain. Some studies suggest that Cambodia's FL will increase by 2.46% of GDP if real GDP increases by 1%. The same study finds that Cambodia, Lao PDR, Myanmar and Vietnam (CLMV countries) experience significant FL values for bananas, cassava, maize, sugar cane, and sweet potato value chains (VC). (Jaroebsathapornkul, 2021).

Food loss valorisation is the conversion of food loss or by-products into higher value products that contribute back to the supply chain (Poritosh, 20213). It appears from our literature review that food loss reduction efforts tend to focus on prevention and lesser on food loss valorisation. Turning FL into new products and feasible business allows farmers to sell more of the food that they produce. Food loss valorisation contributes to a circular

[8] https://doi.org/10.1007/s12571-019-00949-4

economy where useful material, once seen as waste, is recycled back into the supply chain to create new products and closes the food resource loop[9].

AB InBev invested $200 million turning its barley byproducts into a protein and fibre ingredient, thereby resulting in two new businesses producing a dairy-free protein drink and a protein sold to other food manufacturers[10]. Eden Agritech, a company from Thailand uses polysaccharides derived from cassava or corn to develop coating technology to extend fresh produce shelf life by up to five times contributing to loss reduction and value addition for cassava and corn[11].

Key valorisation technologies including anaerobic digestion, fermentation, and composting, transform abundant and low-cost waste biomass into biorefinery products[12]. Food and feed ingredients can be extracted from food processing byproducts, depending on their quality, robustness, and composition. Products that can be recovered include antioxidants, bioactives, biopolymers, biopeptides, antibiotics, industrial enzymes, polysaccharides, activated carbon adsorbent, organic acids, and xanthan gum.

Valorisation is more necessary for tropical crops in developing countries because by nature, tropical crops have a high waste index (proportion of inedible parts), and big volume of crops are wasted after harvesting due to technical and nontechnical deficiencies in value chains (Esra Capanoglu, 2022).

In Cambodia food loss reduction is embedded in overarching policies, food safety law, and food safety management systems and the strategic crop policies such as National Cassava Policy and National Cashew Policy. Cambodia came up with the Roadmap for Food Systems for Sustainable Development 2030 at the 2021 Food Systems Summit with a vision that by 2030, all Cambodians will have access to healthy diets and safe food, with an initial focus on women and children, to break the intergenerational cycle of malnutrition and address the nutritional transition. [27] The vision implies assurance of food safety (access to safe food) and reducing food loss (strengthen local production and distribution) as specified in 3 of the 4 priority thrusts: (1) Healthy diets for all; (2) Resilient livelihoods and resilient food systems; and (3) Governance for a more inclusive food system. [13]

Several overarching RGC national policies has implications on food loss including, improving productivity, quality, and diversification through increased investments in R&D for high value crops, livestock, and aquaculture; model farm development; upgraded processing industry; farming diversification aimed at substituting imports and establishing clean and hygienic wholesale vegetable markets; and better application of Sanitary and Phytosanitary Standards (SPS) system.

Cambodia's Ministry of Agriculture, Forestry and Fisheries (MAFF) Crop Master Plan 2030 envisions Cambodia as a reliable source of high quality, safe, and competitive crops in the global economy while ensuring sufficient volumes of safe food to meet food and nutrition

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[9] https://www.nea.gov.sg/our-services/waste-management/3r-programmes-and-resources/food-waste-management/food-waste-valorisation

[10] https://www.foodbusinessnews.net/articles/17846-investment-in-plant-protein-accelerates#:~:text=Barley%20protein%20offers%20benefits%20in,for%20the%20company's%20barley%20ingredients.

[11] https://www.edenagritech.com/

[12] https://pmc.ncbi.nlm.nih.gov/articles/PMC9204820/

[13] https://pubs.sciepub.com/jfs/12/3/1/

security of its own citizens in a sustainable and climate resilient way. [21] Priority value chains are rice, maize/corn, cassava, mung bean, mango, cashew, pepper, and vegetables.[14]

The Cambodia Climate Change Strategy Plan 2024-2033 and the stock-take of NDC 2.0 conducted in 2024 shows that the progress in emission reduction in Agriculture sector has been slow. Key emission reduction initiatives in this sector are from the valorisation of animal waste (cattle and hogs) the National Bio-digester Programme (NBP).

The goals of NBP include reducing forest degradation and improving quality of life for rural families, as well specific goals of installing of 33,000 units by 2020, long-term adoption and maintenance of installed units, the widespread utilization of bioslurry fertilizer and biogas for lighting, and ultimately, building sufficient capacity to deploy biodigesters throughout the country (Hyman, 2018).

5. Overview of the Six Value Chains

The six major crops—coconut, cashew, cassava, sugarcane, corn, and pepper—are prominent in Cambodia's agricultural sector, both in production scale and economic contribution. Together, they covered a total cultivation area of approximately 1.38 million hectares and generated an estimated USD 3.04 billion in gross production value in 2023 (Figure 3). These crops form the backbone of Cambodia's agricultural economy, supporting livelihoods, rural employment, and export revenues. In 2023 Cassava was the most widely cultivated crop among the six, covering about 705,460 hectares[15], followed by cashew (334,000 ha[16]) and corn (277,000 ha[17]). Coconut, sugarcane, and pepper occupied significantly smaller areas, ranging from 6,935[18] ha for pepper to about 30,287[19] ha for sugarcane (Figure 3A). Yield patterns mirrored cultivation scale to some extent: cassava production reached 14.2 million tons, dwarfing other crops, with corn producing 1.5 million tons and sugarcane 0.68 million tons. The remaining crops—coconut, cashew, and pepper—had relatively modest yields (Figure 3B).

From a value perspective, cassava was the clear leader, contributing approximately USD 1.91 billion—more than 60% of the total value from these six crops in 2023. Sugarcane ranked second with USD 284.92 million, followed closely by cashew (USD 222.75 million) and corn (USD 215.63 million) (Figure 3C). While coconut (USD 75 million) and pepper (USD 71.20 million) had smaller economic shares, they remain important niche commodities with potential for value-added processing and export growth.

[14] Ibid

[15] https://www.canr.msu.edu/resources/cambodia-s-cassava-in-regional-value-chain

[16] https://www.nis.gov.kh/nis/CAS/2023/CAS2023_Report_2_Crop_Production_ENG.pdf

[17] https://www.khmertimeskh.com/501505078/red-corn-production-soars-to-1-7m-tonnes-maff-says/

[18] https://www.khmertimeskh.com/501420426/cambodia-exports-over-100-tonnes-of-kampot-pepper/

[19] https://opendevelopmentcambodia.net/topics/sugarcane/

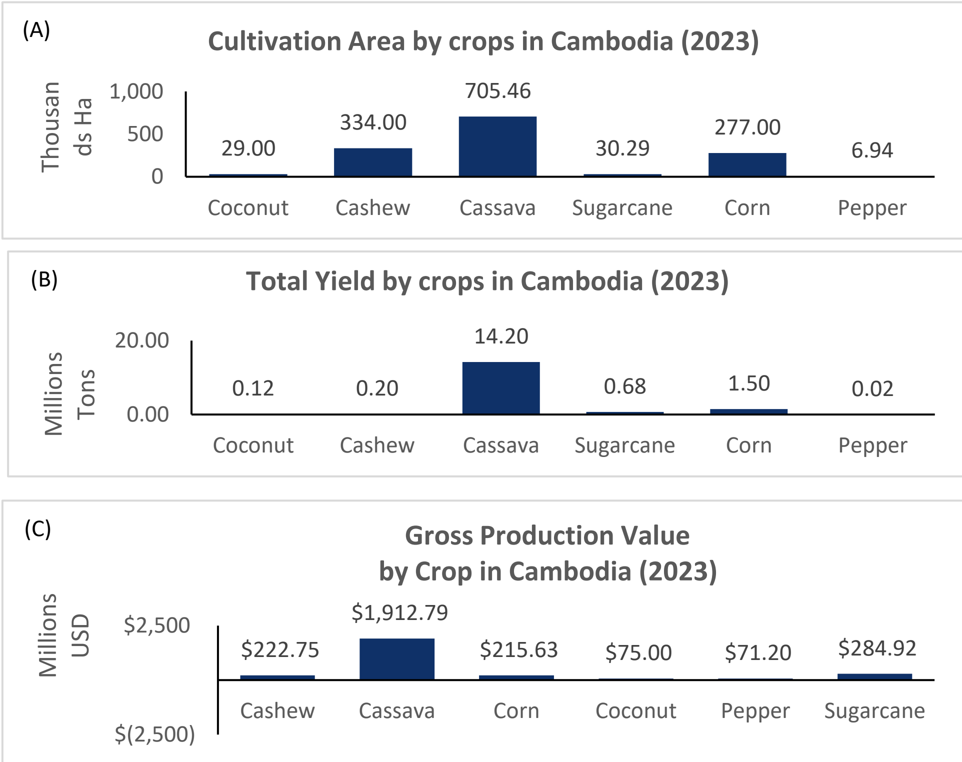

Figure 3: Six crops' production area, yields, production value in Cambodia (2023)

Source: NIS (2023), ODC (2021), CDRI (2024), GIZ (2024), MAFF (2024), SEVEA (2025)

The harvesting schedules of Cambodia's six major crops show significant variation in seasonality and frequency. Cashew, pepper, and sugarcane are harvested once a year, with cashew concentrated in February–May, pepper from January to May, and sugarcane from January to April (**Table 1**). Cassava also has a single annual harvest period, spanning January–February and again in November–December. Maize (corn) stands out for having two distinct harvest seasons—July–August and November–December—providing more than one income opportunity for farmers each year. Coconut is unique among the six crops, as it can be harvested continuously throughout the year, offering a steady supply and more stable income streams compared to the other seasonal crops. This diversity in harvesting schedules not only shapes labor demand and market supply patterns but also influences post-harvest management and value chain planning.

Table 1: Harvesting Schedule of the six crops in Cambodia

Crop	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Cashew		X	X	X	X							
Cassava	X	X									X	X
Maize/corn							X	X			X	X
Coconut	X	X	X	X	X	X	X	X	X	X	X	X
Pepper	X	X	X	X	X							
Sugarcane	X	X	X	X								

Source: SEVEA Food Loss Data 2025

The subsequent chapters provide the details of all the six value chains including the profile of the crops, the mapping, waste hotspots and the valorisation activities in Cambodia.

D. Value Chain Analysis and FLW Hotspot

1. Cashew Value Chain

Cashew – Production & Harvesting Profile

Cambodia has rapidly emerged as the world's second-largest producer of raw cashew nuts, with output increasing from about 50,000 tonnes in-shell in 2014 to an estimated 840,000 tonnes in 2024 and projected to reach 1 million tonnes annually by 2028 (Fitzpatrick et al., 2024). This growth is driven by high-yielding varieties—particularly M23, which accounts for 70–95% of trees in the main producing provinces—combined with favourable climate and soil conditions, recommended planting densities, and improved cultivation practices (Fitzpatrick et al., 2024). Average yields of 1.42 tonnes per hectare are the highest in the world, with Cambodian cashews recognised for large kernel size, good taste, and desirable processing characteristics.

Cultivation is concentrated in provinces such as Kampong Thom, Kampong Speu, Kampong Cham, Preah Vihear and Ratanakiri, with harvesting occurring once a year, mainly from February to March, and occasional early or late harvests depending on weather and variety (Fitzpatrick et al., 2024). Despite rapid growth, the sector remains heavily export-oriented in raw form due to limited domestic post-harvest processing infrastructure—highlighting a key opportunity for value addition (Fitzpatrick et al., 2024).

Cashew – Value Chain Mapping

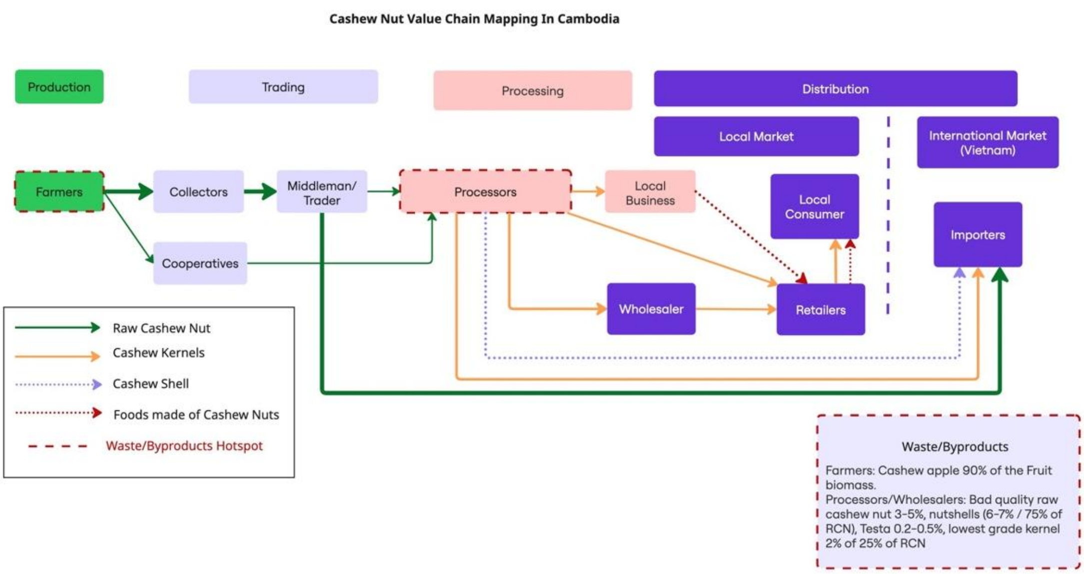

Figure 4 Cashew Nut Value Chain Mapping.

The Cambodian cashew value chain is underpinned by strong primary production from smallholder farmers, often organised in informal groups or cooperatives, alongside a smaller number of medium-scale plantations. Raw cashew nuts (RCNs) are typically channelled through collectors and aggregators, who consolidate volumes from multiple villages before selling to wholesalers and exporters. Over 90% of RCNs are exported to

Vietnam for processing, with only a small proportion handled by domestic processors—both commercial enterprises and community-based initiatives—focused on shelling, kernel extraction, roasting, and packaging.

Key actors in the chain include:

- Producers – Smallholders, farmer cooperatives, and medium-scale plantations.
- Collectors/Aggregators – Village and district-level buyers consolidating RCNs.
- Wholesalers/Exporters – Large traders with cross-border trade links.
- Processors – Limited domestic facilities handling primary and secondary processing.
- Retailers – Small-scale outlets selling processed kernels.

The overall value chain is illustrated in Figure 4, showing product flows from production to domestic and export markets, as well as waste/by-product streams.

Cashew – Loss Hotspots & Causes

Losses occur mainly at the farm and post-harvest handling stages. At the farm level, the cashew apple—about 90% of the fruit's weight—is overwhelmingly left to rot or used as low-value cattle feed. Limited infrastructure for collection, short shelf life, and consumer perceptions of pesticide contamination hinders its use. Other losses result from premature nut drop, pest damage, and incomplete collection in scattered orchards. Post-harvest losses are driven by poor drying and storage practices. Nuts are often dried on the ground or on unprotected tarpaulins, increasing contamination and mould risk. Excessive moisture content leads to aflatoxin risk and reduces kernel quality. Aggregators often mix nuts of different grades, further lowering lot value. In processing—still minimal in Cambodia—losses stem from shelling inefficiencies, kernel breakage, and poor storage of processed kernels. Retail-level losses are negligible due to strong kernel demand, but significant value is lost upstream because of the absence of large-scale domestic processing.

Cashew – Current Valorisation Practices

Valorisation of cashew by-products remains limited and small-scale. Cashew apples, though rich in vitamin C and suitable for juice, wine, vinegar, jam, or animal feed, are mostly discarded. Only a few pilot initiatives—often NGO-led—have attempted small-batch products, but these face challenges of perishability, collection logistics, and low consumer acceptance. Domestic processing of nuts is concentrated in small cooperatives and enterprises producing roasted or flavoured kernels for niche local and tourist markets. Cashew shells and testa are occasionally used for kiln fuel or composting, but no structured waste-to-value system exists. Cashew shell liquid (CNSL) extraction—common in neighbouring countries—is not yet practised in Cambodia.

2. Cassava Value Chain

Cassava Value Chain – Production & Harvesting Profile

Cassava is Cambodia's second-largest crop after rice, cultivated predominantly by smallholder farmers across the country. It is generally planted between February and April and takes around 9–10 months to mature, with harvesting concentrated in the November–January period (Keo, Sim, & Sey, 2024). Over the last two decades, planted area has expanded significantly—from less than 30,000 ha in 2004 to over 705,000 ha in 2023—driven by strong export demand from neighbouring countries (Keo, Sim, & Sey, 2024).

Yields average 19–20 tonnes/ha, with some provinces exceeding this benchmark. The largest production hubs include Battambang, Banteay Meanchey, Oddar Meanchey, Kratie, Kampong Thom, Tbong Khmum, and Pailin, with Battambang alone producing over 3.27 million tonnes in 2023 (Keo, Sim, & Sey, 2024). In these areas, mechanization is gradually replacing manual cultivation, although many farmers still rely on conventional methods and minimal input use (Keo, Sim, & Sey, 2024).

The crop's seasonality and perishability strongly influence harvesting practices and market flows. Cassava roots deteriorate within 24–72 hours of harvest, prompting most farmers to either sell fresh roots quickly to collectors or slice and sun-dry them into chips to extend shelf life (Keo, Sim, & Sey, 2024). Standard farm-level practice involves cutting roots into smaller unpeeled pieces and sun-drying on tarpaulins for less than a week to reach ~14% moisture content. This processing stage is critical for meeting buyer specifications, with dried chips fetching 600–700 riel/kg (~USD 0.15–0.175) compared to lower fresh root prices (Keo, Sim, & Sey, 2024). Quality and starch content peak during the early harvest months (January–March), aligning with feed processors' peak purchasing period (Keo, Sim, & Sey, 2024). The majority of Cambodia's cassava output—about 96% of the 14 million tonnes produced in 2023—is exported, primarily to Thailand and Vietnam, with only a small proportion retained for domestic processing into native starch and animal feed (Keo, Sim, & Sey, 2024)

Cassava – Value Chain Mapping

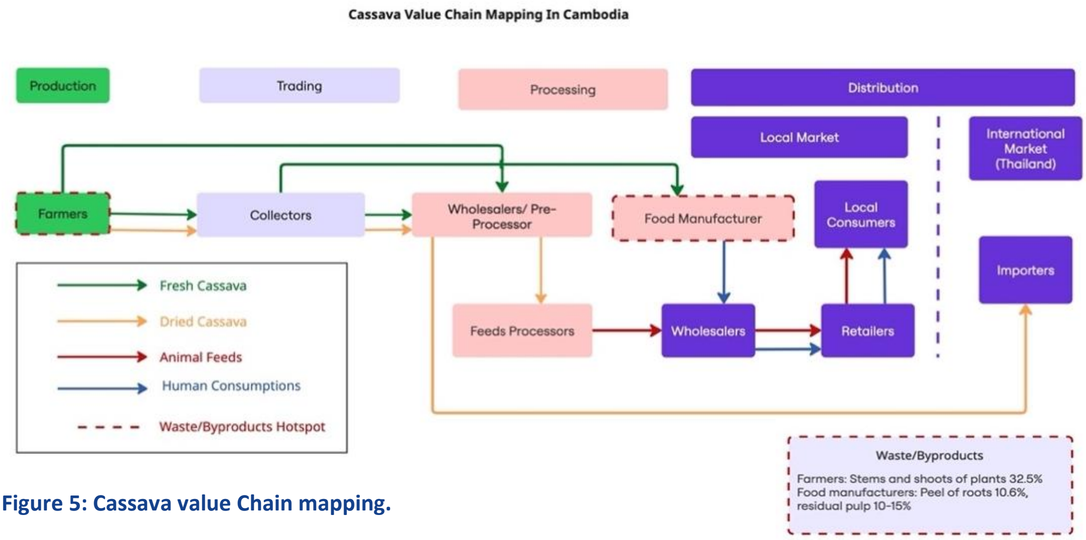

Figure 5: Cassava value Chain mapping.

The Cambodian cassava value chain is characterized by a high degree of export orientation, with limited domestic processing capacity. At the upstream level (shown in Figure 5), smallholder farmers cultivate cassava on plots averaging 2–3 ha, supplying either fresh roots or farm-dried chips. Their output is channeled to local collectors, who operate as intermediaries between farms and processing or trading points. Collectors typically own 5–6 tonne capacity trucks, purchasing directly from farmers and transporting to wholesalers or silo operators.

Silo operators (pre-processors) aggregate large volumes of both dried and fresh cassava from multiple collectors and farmers. They play a critical role in secondary drying—using concrete yards and tarpaulins to ensure chips meet the required ≤14% moisture content—before selling to export traders or domestic processors. The majority of dried chips are exported to Thailand and Vietnam, while smaller quantities enter the domestic supply chain for animal feed production (where chips make up ~30% of cattle feed formulations). Fresh roots for native starch production are purchased directly by local starch factories, which process them within 24 hours of harvest to preserve starch quality.

Cassava – Loss Hotspots & Causes

Figure 6: Dried Cassava Chips was stored in a Silo's warehouse in Battambang Province

Losses in the Cambodian cassava value chain occur at multiple stages, but the most significant hotspots are linked to post-harvest handling, drying, and storage. At the farm level, deterioration begins rapidly—within 24–72 hours after harvest—due to high moisture and enzymatic activity in fresh roots. Farmers without immediate buyers or drying capacity face starch degradation and weight loss, reducing market value. Inadequate drying infrastructure (often just tarpaulins on bare ground) exposes chips to rain and dust contamination, leading to mould growth and quality downgrades. Losses also arise when roots are harvested during wet weather, making it harder to achieve target moisture levels and increasing spoilage risk.

At the processing and aggregation stages, silo operators and wholesalers encounter further losses if drying is incomplete or poorly managed. Even with concrete yards, rain exposure or slow drying can push moisture above the 14% threshold, leading to fungal contamination and rejection by buyers. Quality deterioration is also common when chips are stored in poorly ventilated warehouses, encouraging mould and mycotoxin development. For fresh cassava destined for starch production, delays in delivery to factories significantly lower starch content, forcing processors to downgrade batches or reduce purchase volumes. Additionally, competition from export markets—particularly Vietnam during peak buying periods—diverts high-quality roots away from local processors, sometimes resulting in overstocking of lower-grade material that is more prone to loss.

Cassava – Current Valorisation Practices

Cassava in Cambodia generates several by-products during cultivation and processing, yet most remain underutilised. At the farm level, stems and shoots (about 32.5% of plant biomass) are partly reused for replanting, with excess often burned in fields. Leaves are occasionally fed to livestock but are rarely collected or traded systematically. During processing, cassava peels—which make up roughly 10.6% of root weight—are the primary by-product, produced during cleaning at starch factories. These are typically discarded, with no observed large-scale valorisation into animal feed or compost, despite their potential as a nutrient-rich input. Residual pulp from starch extraction, representing 10–15% of fresh root weight, is sometimes fed to animals in an unprocessed form but more commonly disposed of.

Although Cambodia has not yet developed a strong by-product economy for cassava waste, regional and policy references indicate potential pathways. The National Cassava Policy

(2020–2025) promotes conversion of cassava processing wastewater into biogas and organic liquid fertilisers, but adoption remains minimal. International models—such as Thailand's use of cassava pulp for animal feed, mushroom media, biogas, and bioethanol—demonstrate feasible technologies like fermentation, anaerobic digestion, and composting. A few Cambodian initiatives, such as household biodigesters supported by the National Biodigester Programme, show how cassava residues can be integrated with animal manure to produce cooking fuel and fertiliser, but these remain small-scale and mostly farm-based rather than integrated into industrial processing operations.

3. Corn/Maize Value Chain

Corn/Maize – Production & Harvesting Profile

Corn (maize) production in Cambodia is dominated by red or yellow maize, which is primarily grown for the livestock feed industry due to its high starch and protein content. Smaller volumes of white (waxy) maize are cultivated for human consumption. The crop is concentrated in the northwestern provinces—Battambang, Banteay Meanchey, and Pailin—with additional production in Pursat, Kandal, and Tboung Khmum (EuroCham Cambodia, 2023). In 2023, maize occupied just over 275,000 hectares nationally, producing around 1.5 million tonnes at an average yield of 4.8 tonnes per hectare (EuroCham Cambodia, 2023). Within Battambang, smallholder farmers dominate, and maize has adapted well to upland soils with adequate rainfall, benefitting from proximity to Thai markets (MI, 2020; EuroCham Cambodia, 2023).

Farmers typically plant maize twice a year. The first crop is sown between March and April and harvested in July–August, while the second crop is planted in July–August and harvested in November–December. Maturation takes 3–4 months and yields in Battambang range from 3 to 6 tonnes per hectare depending on soil fertility, input use, and seasonal conditions (MI, 2020). Harvesting is mostly done manually, as mechanical harvesting is avoided due to accessibility issues and the high grain loss rates associated with current machinery designs. Ears are collected without husks, packed in 50–70 kg polybags, and transported to collectors or processors using hand tractors or small trucks. In the wet season, most maize is sold on the cob to avoid post-harvest losses from high humidity, pest pressure, and limited drying and storage capacity (MI, 2020).

Corn/Maize – Value Chain Mapping

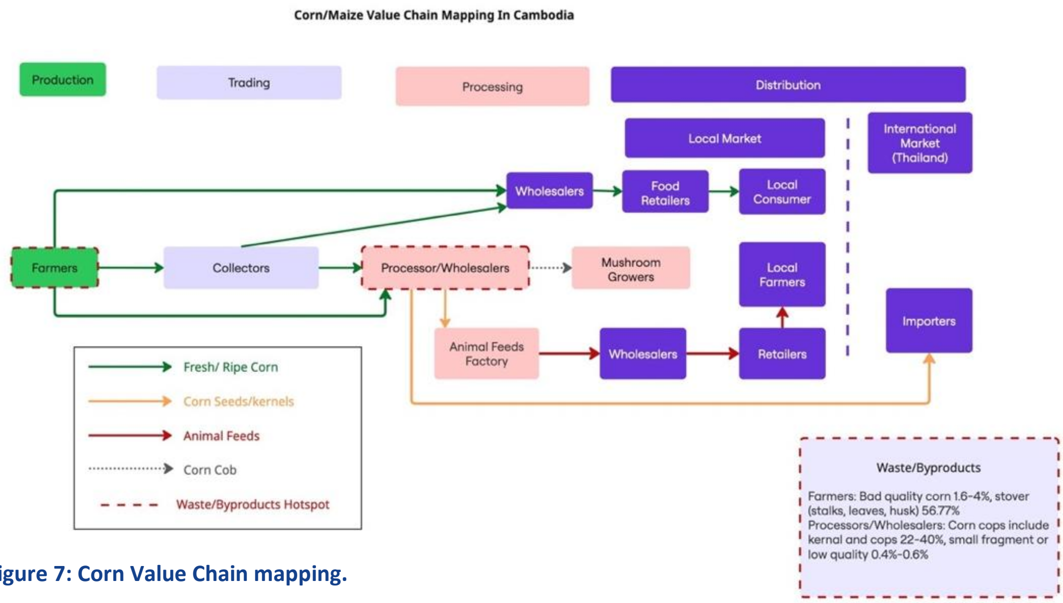

Figure 7: Corn Value Chain mapping.

The Cambodian corn value chain is driven largely by smallholder farmers cultivating hybrid maize varieties, supported by agro-input suppliers including seed and chemical distributors. Production is geographically concentrated in Battambang, Banteay Meanchey, and Pailin, with farmers producing two crops per year and harvesting mainly by hand. Post-harvest, maize flows through local collectors who bulk and transport it to pre-processing facilities or directly to buyers, depending on seasonal prices and cross-border trade conditions. Semi-processors (silo operators) undertake shelling, drying, cleaning, and grading, supplying both domestic feed mills and cross-border markets. Licensed exporters dominate shipments to Thailand's feed industry, while domestic buyers like Mong Rithy Group and CP Group procure for local feed production. Although Cambodia imports large quantities of maize for feed, cross-border sales remain important for farmgate liquidity and market diversification.

Key actors in the chain include (shown in figure 7):

- Producers – Smallholder farmers, medium-scale farms.
- Collectors/Assemblers – Village and district-level buyers consolidating maize from multiple farms.
- Processors/Silo Operators/Wholesalers – Facilities for shelling, drying, cleaning, and grading maize.
- Exporters – Licensed companies handling cross-border sales to Thailand and other markets.
- Feed Processors – Domestic manufacturers such as CP Group and Mong Rithy Group.
- Retailers – Domestic outlets and feed distributors supplying farmers and livestock operators.

Corn/Maize – Loss Hotspots & Causes

Losses in the Cambodian corn value chain occur at multiple stages, starting at the farm level where husks, leaves, and stalks—which make up over half of the plant biomass—are routinely left in the field and often burned. During harvest, especially in the wet season, high humidity and limited access to drying or storage facilities force farmers to sell maize on the cob quickly, sometimes before optimal maturity, leading to reduced kernel quality. Defective ears—damaged by mould, pests, or poor pollination—are partially diverted to on-farm livestock feed, but the remainder is discarded. Manual handling and transportation in open trucks or hand tractors also expose maize to mechanical damage and weather-related deterioration.

Figure 8 Corn and Cashew Nut subjected to sun-drying by a micro-processor in Battambang. The ground corn grain is then sold to customers as chicken feeds.

At the processing stage, incoming maize often has a moisture content above 30%, which increases breakage during shelling and heightens the risk of spoilage if drying is delayed. During peak harvest, processing facilities face capacity bottlenecks, resulting in some loads being left outside in the rain, further reducing quality. Processors typically reject 100–

200 kg of defective kernels per 5–6 tonne truckload, returning them to farmers. Additional losses occur through the separation of small fragments, fines, and tip-cap-attached kernels during cleaning; while some are sold as low-value animal feed, much remains underutilised. Market-side rejections are common when shipments fail to meet buyer specifications on moisture content, cleanliness, and kernel integrity, with these quality issues often traceable to earlier stages in harvesting, handling, and drying.

Corn/Maize – Current Valorisation Practices

Current valorisation of corn by-products in Cambodia is relatively limited and concentrated at the processing stage. Corn cobs are the most actively utilised by-product, primarily burned as fuel in hot-air drying systems at silo and processing facilities. In the past, surplus cobs were sold to mushroom growers as a substrate, but this demand has declined in recent years, resulting in many cobs being left to rot. Small fragments, fines, and low-quality kernels separated during cleaning are occasionally sold to local farmers for use as cattle or poultry feed, providing a minor additional revenue stream for processors.

At the farm level, valorisation is minimal. Defected or pest-damaged corn that is still edible is often used as on-farm feed for livestock, while the remaining unusable kernels are discarded. Corn stover—including husks, stalks, and leaves—is generally burned or left to decompose in the field, despite its potential as raw material for composting, mulching, biochar production, or biomass energy. Although research and pilot projects in Cambodia and neighbouring countries have demonstrated possible uses for corn residues in biodegradable packaging, paper, composite materials, and biofuels, these applications have yet to be adopted commercially within the Cambodian maize sector.

4. Pepper Value Chain

Pepper – Production & Harvesting Profile

While Kampot province—renowned for its GI-protected Kampot pepper—remains the flagship production area, other provinces such as Tbong Khmum, Mondulkiri, and Ratanakiri (GIZ, 2025) also contribute significantly to national output valued at around USD 71.2 million in 2023 (**Figure 3**). Cultivation in Kampot covers approximately 325 hectares (289 ha harvested), producing four main product types—black, red, white, and fresh green pepper—sold at USD 17–30/kg through KPPA channels, with premium retail prices from vertically integrated farms reaching USD 59–70/kg[20]. Nationally, production is dominated by smallholder farmers, with limited cooperative membership and weak sector organization. Most pepper is exported raw or semi-processed, often unofficially to Vietnam for further processing and re-export, which limits domestic value addition (GIZ, 2025).

Production systems are highly sensitive to climate variability, relying on rainfall and small-scale irrigation, making them vulnerable to drought and extreme heat (GIZ, 2025). In 2024, severe weather caused yield losses of up to 50% in some areas, and overall cultivated and harvested areas declined. Operating costs in Cambodia average USD 2.30–2.65/kg, about 33% higher than in Vietnam, constraining competitiveness (GIZ, 2025). Despite these challenges, there are signs of market diversification, with Cambodia exporting 30 tonnes of black pepper directly to China in April 2024 and recording nearly USD 10 million in pepper exports in Q1 2024 (Mathew, 2024). Global black pepper inventories have also dropped below one year's supply for the first time since 2019 (Nedspice, 2024), creating potential

[20] Interview with KPPA

opportunities for Cambodian producers—provided resilience, quality standards, and local processing capacity can be strengthened.

Pepper – Value Chain Mapping

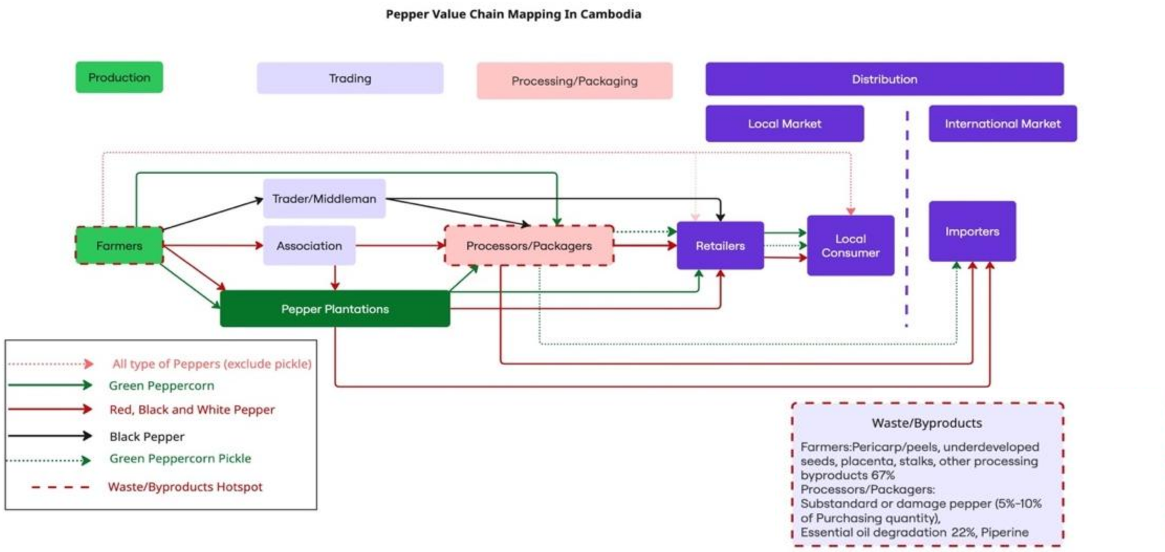

Figure 9: Black Pepper Value Chain mapping.

The Cambodian pepper value chain is characterised by a mix of formal GI-certified channels (notably for Kampot pepper) and informal trade flows dominated by cross-border exports to Vietnam (GIZ, 2025). Production is undertaken mainly by smallholder farmers, with some vertically integrated large plantations controlling their own processing and export (GIZ, 2025). Farmer organisations such as the Kampot Pepper Promotion Association (KPPA) enforce GI quality standards, but nationally, farmer cooperative participation remains low, and value chain coordination is weak (GIZ, 2025).

Figure 9 illustrates the core actors and product flows from production to domestic and international markets, along with by-product streams and points of loss.

Key Actors:

- Producers
  - Smallholder farmers (majority) and some medium to large plantations.
- Collectors / Traders
  - Local collectors purchase substandard or non-GI pepper from farmers, paying lower prices (USD 3–7/kg).
  - In GI channels, collection is mainly handled by member companies, bypassing informal traders.
- Processors
  - GI-certified processors (e.g., Farmlink, La Plantation, Sothy's Farm) handle cleaning, sorting, grading, packaging, and in some cases value-added processing (pickled pepper, pepper tea, stem fertiliser).
  - Non-GI processors typically deal with bulk pepper for local consumption or export with/without formal certification.
- Wholesalers / Exporters
  - GI-certified exporters sell to high-value international markets (EU, China, niche gourmet buyers).
  - Non-GI pepper largely flows to Vietnam for reprocessing and re-export.

- Retailers
  - Large plantations and some processors sell directly via on-site stores, online platforms, or tourist outlets, commanding significantly higher retail prices.

Pepper – Loss Hotspots & Causes

From interviews with stakeholders, post-harvest losses in Cambodia's pepper sector occur primarily during handling, drying, grading, and storage. At the farm level, freshly harvested pepper spikes are threshed, boiled, and sun-dried for three to five days. Inadequate drying infrastructure and exposure to rain during this period can result in mould growth, discolouration, or uneven moisture levels. Subsequent sorting and grading remove 5–10% of the harvest as substandard, which is sold at reduced prices of USD 3–5/kg to local traders. Extended storage in poor conditions can further degrade quality, with studies showing losses of essential oil content by around 22%, piperine by 19%, and colour by 31% over a 12-month period. These factors are especially critical for high-value markets, where quality deterioration directly impacts exportability and price premiums.

Losses also occur at the processing stage. Cleaning, grading, and packaging typically result in 5–10% of the pepper being rejected as damaged or defective, which is then sold to restaurants or low-value buyers at USD 3–5/kg. Processing generates about 5 kg of pepper dust per tonne of pepper handled, a by-product historically used as a natural pesticide but found to be ineffective locally due to insect resistance. In non-GI supply chains, where quality controls are less rigorous, inadequate hygiene and drying protocols can lead to microbial contamination, making the pepper unsuitable for premium export markets (GIZ, 2025). Together, these losses from post-harvest to processing stages reduce both the volume and quality of pepper available for high-value sales, limiting the sector's overall competitiveness (GIZ, 2025).

Pepper – Current Valorisation Practices

In GI-certified supply chains, post-harvest losses are minimised through strict grading, and some by-products are repurposed into value-added products. For example, a Kampot processor produces pickled green pepper, pepper stem tea, and uses unusable peppercorns as organic fertiliser for plants. Another processor sorts and re-grades downgraded pepper for sale to local restaurants and hotels, ensuring even lower-quality pepper generates revenue.

Processing by-products include pepper dust (around 5 kg per tonne processed), which has been trialled as a natural pesticide but found ineffective locally due to insect resistance. Stalks and stems from harvested pepper spikes are sometimes dried and made into tea, though most are left to decompose at the farm. In some small-scale initiatives, stems and damaged peppercorns are explored for extraction of piperine and other bioactive compounds for potential use in pharmaceuticals and health supplements (Lwamba, 2023; Phan, 2023), based on international research, but this remains at a study stage rather than commercial practice in Cambodia.

5. Coconut Value Chain

Coconut – Production & Harvesting Profile

Coconuts are widely cultivated in Cambodia's southwestern provinces—particularly Kampong Speu, Kampot, Takeo, Preah Sihanouk, Koh Kong, and Kep—with expansion into inland areas such as Battambang (GIFT, 2017; CPSA, 2020). In 2023, national production reached 258,935 tonnes (+2.4% YoY) from 19,998 ha planted, of which 14,225 ha were harvested; Kampong Speu contributed 22.8% of output, Kampot 21.1%, and Battambang 9.5% (Vayuth, 2024). Three main varieties are grown: fragrant (aromatic) and Toke coconuts, harvested young for water and commanding higher fresh prices (16,000–20,000 riel/dozen), and the larger, slower-maturing Kapal coconut, preferred for oil processing (2,000–2,500 riel/mature fruit)[21]. Most production comes from smallholdings under 2 ha, intercropped with other perennials, yielding 5–15 nuts/tree/month for young varieties and 50–70 nuts/tree/year for Kapal (CPSA, 2020). Production is year-round but can drop during prolonged dry periods; climate impacts in 2024 notably reduced yields in several areas.

Market demand is dominated by fresh domestic consumption, driven by the popularity of coconut water and health-conscious diets, while a smaller share of mature nuts is processed into virgin coconut oil, vinegar, and other products (Vayuth, 2024; CPSA, 2020). Kampot alone has about 4,868 ha (598,764 trees), though farmers are shifting from Kapal to quicker-bearing fragrant and Toke varieties. Processing-oriented supply remains limited, as many farmers prefer the higher immediate returns from young coconuts. In 2023, Cambodia and China signed a phytosanitary protocol for fresh coconut exports, prompting MAFF to register plantations and processing facilities for the Chinese market (Vayuth, 2024).

Coconut – Value Chain Mapping

Cambodia's coconut value chain is predominantly smallholder-driven, with most farms under 2 ha and three main varieties—fragrant, Toke, and Kapal—supplying distinct market segments. Fragrant and Toke coconuts are harvested young and sold mainly for fresh drinking, while Kapal coconuts are sometime left to mature for oil production.

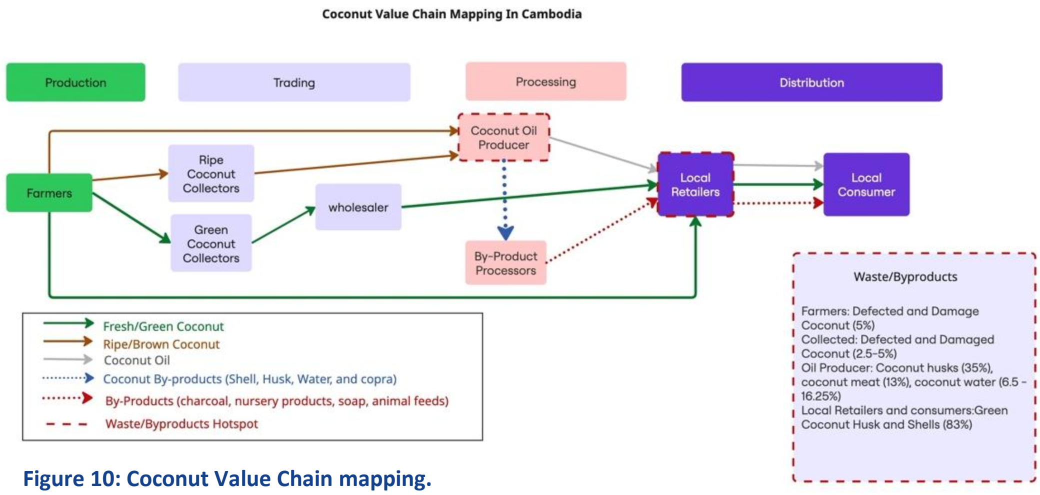

Figure 10: Coconut Value Chain mapping.

Figure 10 shows the core actors and product flows from production to distribution, along with by-product streams and loss hotspot.

- Production (farmers) – Farmers cultivate 20–40 trees on average, harvesting year-round. Young coconuts are sold in dozens directly from farms, often to local collectors. Pre-harvest losses occur due to pests, with management relying on chemical or homemade organic pesticides. Climate change, particularly prolonged drought, has reduced yields in some areas.

[21] Field Data Survey with Coconut Farmers in Kampot.

- Collection & Trading –Young coconut collectors operate trucks (5–15 t capacity), loading 8,000–10,000 coconuts over 2–3 days before distributing to urban markets, retail shops, and wholesalers. Wholesalers typically use motorbike carts, buying 150–250 coconuts daily for distribution to street vendors and small retailers. Mature coconut collection is less common; processors often source directly from farmers due to limited supply.
- Processing –Processors:
  - Coconut oil processors (mainly small-scale) prefer mature Kapal coconuts for higher kernel yield. One processor may handle 20,000–30,000 nuts annually, producing 300–500 litres/month of virgin coconut oil (VCO) sold at $28/L. Damaged nuts are used to produce lower-grade oil for soap making ($1/bar).
  - By-product processing is notable: husks sliced for compost (1,000–1,500 riel/kg), shells sold for charcoal (250 riel/kg), meal fermented for animal feed, and coconut water sold to vinegar makers (1.5M riel/tonne). Social enterprises like CoCo de Takeo convert husks into coir products, footwear, rope, and handicrafts; Khmer Green Charcoal turns shells into biochar briquettes.
- Distribution & Retail – Retailers and street vendors primarily sell fresh coconuts for juice. Unsold stock may be turned into coconut jelly or other products to reduce waste. Fresh coconuts are consumed domestically, though the sector is positioning for export to China under the new phytosanitary agreement.

Coconut – Loss Hotspots & Causes

Losses in the Cambodian coconut value chain occur at multiple points, with quality degradation and underutilisation of by-products as recurring themes. At farm level, pre-harvest losses are mainly due to insect pests damaging fruits; without effective control, affected nuts are often unmarketable. Harvest and handling damage occurs when nuts are dropped from trees or mishandled during cutting, especially for green coconuts, causing cracks or bruising that affect the marketability. This damaged or defective nuts (about 5% of production) may be consumed domestically by the farmer or discarded if unsuitable for consumption. At trading stage, damage during loading, transport, and unloading results in an additional 2.5–5% loss, particularly when coconuts are stacked without cushioning or transported over long distances in open trucks. Delays in distribution (2–3 days to fill and another 2–3 days offload trucks) can prolong the exposure to the risk of loading and transporting.

At the processing stage, the main challenge is supply shortages of mature Kapal coconuts, leading to underutilised capacity. Damaged mature nuts are downgraded for soap or low-grade oil production, reducing margins. In areas without by-product utilisation systems, husks, shells, and coconut water may be discarded. In distribution and retail, unsold coconuts—particularly green ones—spoil if not sold within a week or two. In urban juice vending, an estimated 83% of a coconut's biomass (mainly husk and shell) can become waste when discarded without recycling or composting, representing a major untapped resource stream.

Coconut – Current Valorisation Practices

By-product use in Cambodia's coconut sector varies significantly by location and actor, with some processors demonstrating full-product utilisation while others discard most residues. Where valorisation systems are in place, mature Kapal coconuts can generate multiple revenue streams: husks sliced and sold for compost or growing medium (1,000–1,500 riel/kg), shells sold for charcoal production (250 riel/kg), coconut meal fermented with molasses for animal feed, and coconut water sold to vinegar producers (1.5M riel/tonne). Damaged nuts are diverted to lower-grade oil for soap production.

Several enterprises have emerged to expand coconut waste utilisation. CoCo de Takeo, a social enterprise, transforms husks into coir products such as mats, rope, footwear, and handicrafts, alongside compost production. Khmer Green Charcoal in Phnom Penh converts coconut shells and recovered coal into high-energy, long-burning briquettes, reducing reliance on forest-derived charcoal. Smaller processors and artisans also carve shells into cups, ornaments, and souvenirs for local and tourist markets.

Despite these examples, valorisation is not widespread. Many smallholders and fresh coconut vendors—especially in urban areas—discard husks and shells, leaving a large portion of coconut biomass unutilised. Where organised collection and processing exist, however, coconut by-products can support circular economy outcomes, generating additional income for producers and reducing environmental waste.

6. Sugarcane Value chain

Sugarcane – Production & Harvesting Profile

Sugarcane is an important industrial crop in Cambodia, cultivated mainly in Kampong Speu, Koh Kong, Oddar Meanchey, and Preah Vihear provinces (ODC, 2021). In 2023, the crop covered approximately 30,290 hectares, producing 0.68 million tonnes with a gross production value of USD 284.9 million (**Figure 3**); yields averaged around 10.76 t/ha nationally, though large plantations achieved 50–80 t/ha compared to smallholders' 20–25 t/ha (NIS, 2023; ODC, 2021). The sector is split between smallholder farms (typically <3 ha) and large-scale plantations under Economic Land Concessions (ODC, 2021). Two main varieties are grown: honey sugarcane, valued for juice production, and bamboo sugarcane for refined sugar manufacturing[22]. Harvesting occurs annually from February to May, with irrigation requirements limiting expansion to areas with unreliable water access (ODC, 2021). Despite yield declines over the past decade, total production has risen due to increased cultivation area and industrial-scale operations (NIS, 2023).

Processing capacity is concentrated in major factories such as Phnom Penh Sugar Co. in Kampong Speu (up to 102,000 tonnes of white sugar per year) (Socheath, 2020), alongside other large investments in Koh Kong and Preah Vihear (ODC, 2021). However, mechanisation rates remain low compared to regional leaders, with most smallholders relying on manual harvesting due to cost, terrain, and farm size constraints (Khmer Times, 2021). Large plantations supply directly to sugar mills, while smallholders sell through collectors or local wholesalers, often facing price volatility, drought impacts, pest damage, and quality deterioration risk during the rainy season. Beyond sugar, sugarcane by-products such as bagasse, molasses, press mud, and tops offer significant valorisation potential for energy, bioethanol, animal feed, and bioproducts (Singh et al., 2021; Poria et al., 2022; Ungureanu et al., 2022; Ding, 2024; Matsueda & Antunes, 2024), but large-scale biofuel production remains unrealised in Cambodia (ODC, 2021).

[22] Survey with Farmers in Kampong Speur Province

Sugarcane – Value Chain Mapping

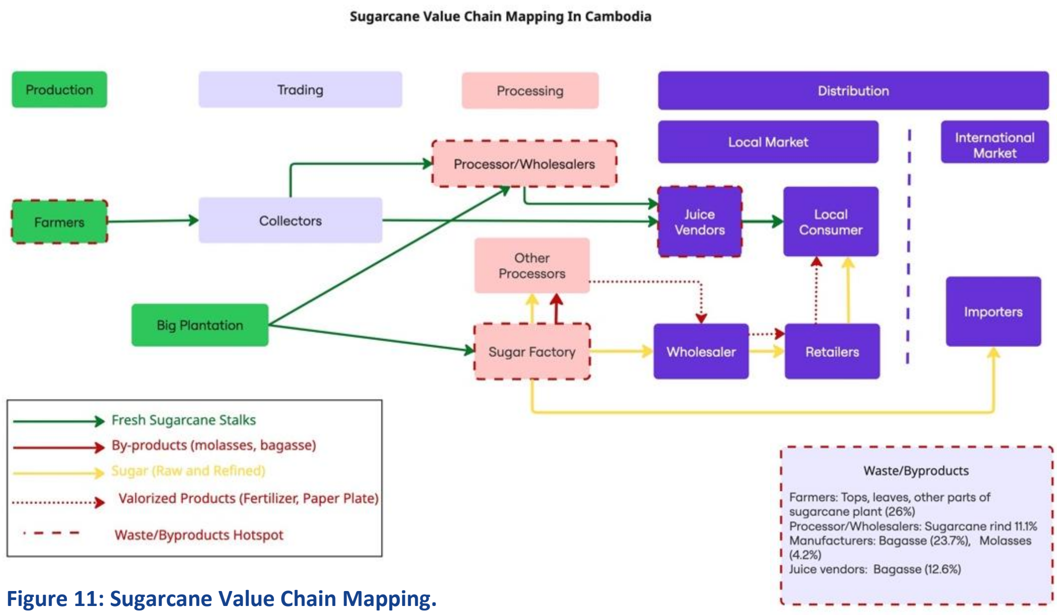

Figure 11: Sugarcane Value Chain Mapping.

The sugarcane value chain in Cambodia spans production, trading, processing, and distribution (shown in Figure 11), with distinct roles for smallholders, large plantations, intermediaries, processors, and end-market vendors. Smallholder farmers (typically <3 ha) cultivate mainly honey sugarcane for juice markets, achieving yields of 20–25 t/ha and selling through local collectors or directly to retailers. Large plantations (1,000–10,000 ha) focus on bamboo sugarcane for refined sugar, operating under Economic Land Concessions and supplying mills such as Phnom Penh Sugar Co. at USD 33–36 per tonne.

Collectors purchase whole crops from farmers, hiring them for harvesting and transporting cane to agreed delivery points. Some act as retailers or supply wholesalers, sourcing from multiple provinces including Kampong Speu, Siem Reap, Battambang, Takeo, and Kandal. Wholesalers/retailers grade stalks (2 m, 1.5 m, 1 m) and sell to juice vendors or consumers, with frequent losses from rain damage or disease. Processors include sugar factories producing white, refined, and raw sugar, as well as small-scale actors valorising bagasse into paper plates or eco-firewood. Juice vendors buy 2–3 batches twice a week from wholesalers, selling fresh juice directly to consumers. The chain is supported by input suppliers (fertilisers, irrigation equipment) and transport providers, but is constrained by low mechanisation, fragmented smallholder production, and limited coordinated marketing.

Sugarcane – Loss Hotspots & Causes

Losses in sugarcane occur at multiple points in the value chain, with the most significant hotspots at the farm and retail levels. In production, climate-related stresses such as drought and irregular rainfall reduce cane maturity and sugar content, while pest infestations cause physical damage to stalks. Delayed harvesting—often due to low market demand—exposes cane to the rainy season, leading to spoilage and diminished sucrose levels. During trading and retail, harvested stalks are prone to physical damage from handling and transport, particularly when loaded and unloaded manually or transported on rough terrain. Exposure to rain accelerates deterioration, making the cane unsuitable for juice extraction or premium-grade sales. Wholesalers in Kampong Speu report losing around 10 batches per 300-batch shipment every 2–3 days due to broken stalks, disease signs, or low sugar content. At the juice vending stage, bagasse waste is generated after extraction, with no structured collection or reuse in most cases.

Sugarcane – Current Valorisation Practices

Figure 12: Sugarcane Stalks are prepared for new season planting in Kampong Speur.

Sugarcane processing yields several by-products with potential economic value, though utilisation in Cambodia remains limited and largely informal. In large sugar mills, bagasse (about 23–40% of cane weight) is sold for paper plate manufacturing or used on-site for boiler fuel. Smaller-scale initiatives in Siem Reap and Phnom Penh have demonstrated eco-firewood production by compressing sugarcane pulp with wood chips, and biodegradable tableware manufacturing by drying and pulping bagasse. Molasses (around 4.2% of cane weight) is typically sold for fertiliser production, while press mud is rarely valorised despite its nutrient-rich potential as organic fertiliser or feed ingredient.

In juice vending, extracted bagasse (about 12–13% of stalk weight) is generally discarded or occasionally given away as cattle feed. Sugarcane tops and leaves, left after harvesting (26% of biomass), are mostly burned in fields, though globally they can be used for bioenergy, bioplastics, or high-protein livestock feed. Research and pilot projects have explored converting bagasse and tops into bioethanol or biogas, but no commercial-scale biofuel production currently exists in Cambodia. The absence of structured collection systems, investment in processing infrastructure, and market linkages limits the scale and consistency of these valorisation activities.

E. FLW Analysis and Valorisation Opportunity

The analysis of food loss and waste across six major crops in Cambodia shows significant inefficiencies along their value chains, with varying loss hotspots depending on the crop (**Table 3 in Appendix 1; Figure 13**). Overall, the quantitative analysis (Figure 13) highlights that maize has the largest absolute waste per hectare, followed by sugarcane and cassava. However, in terms of relative proportional losses, cashew and coconut are particularly critical: cashew for its massive biomass losses at the farm gate, and coconut for its downstream distribution waste.

Economic costs of FLW

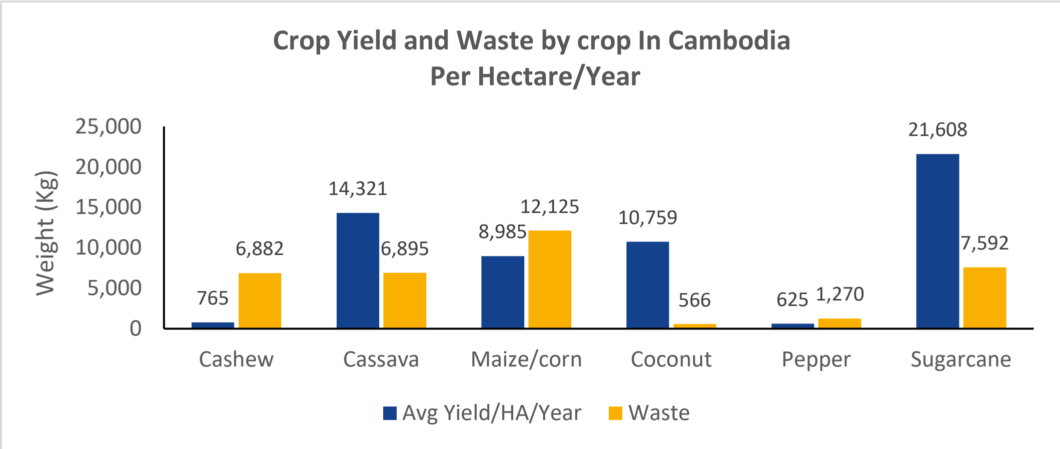

Figure 13: Crop Yield and Waste in Cambodia per Hectare/Year, Source: SEVEA Food loss data 2025

Farmers lost substantial harvest, ranging from 21.2% for sugarcane to 55.24% for coconut; this was the sum of harvest loss due to reduced yield and postharvest loss due to handling deficiencies with the former contributing larger part than the latter (Table 2). In peppers, the loss value represents only postharvest loss equivalent to about 80% price reduction of 5-10% of produce volume with reduced quality. In terms of volume loss per farmer, pepper had the lowest (more or less 100 kg) while cassava the highest (almost 15 tons). This loss volume reduced farmers' income per harvest from about USD136 for coconut and USD446 for corn to over USD2,000 for cassava and sugarcane. Despite the least volume loss of peppers, the maximum loss value of almost USD4,000 was the highest due to very high market price of USD17-30 per kg in contrast to about USD1.0 or less for other crops. These loss volume and value will increase per year for some crops with multiple harvests (e.g. coconut, pepper) or with at least two growing seasons (e.g. corn).

Projecting the farm-level loss at the country level using total hectarage and average farmers' yield per year shows that the loss volume and value are enormous (Table 2). Total loss ranges from as low as 177.7 tons for peppers valued at about 3 million USD to almost 4 million tons for cassava valued at 559 million USD. Losses of the 6 crops totalled about 5 million tons worth almost 1 billion USD.

Postharvest loss of other value chain actors was also significant (Table 3). Processors of cashew and corn and coconut collectors discarded 2-7% of produce due to defects while copra producer incurred 13% loss. The resulting volume and value of loss varied - about 7,000 to over 16,000 kg worth USD7,700-18,000 for cashew; 20,000-59,400 kg valued at USD2,800-8,316 for corn; 12,480-24,960 kg worth USD7,363-14,726 for coconut; and 2,516-3,774 kg and USD7,447-11,171 for copra. Extending this loss magnitude at the national level similar to farm-level loss is constrained by lack of data.

The foregoing shows the enormity of the FLW problem of the 6 food crop products. Several factors contribute to this, including lack of awareness of the importance of FLW reduction, inadequate capacity, limited access to technologies and facilities, imbalanced priorities with more attention to increasing production, and weak policy, infrastructure, coordination and incentive systems. Addressing FLW certainly has strong positive impact on the economy and contribute to the global agenda (UN SDG 12.3) to reduce food losses along production and supply chains, including postharvest losses.

Table 2. Product volume and value of FLW in crop value chains at the farm level.

Value chain	FLW (%)			Total production/ famer (kg) (B)	FLW volume and value / farmer / harvest			FLW volume and value at country level / year				
	Harvest[1]	Post-harvest[2]	Total (A)		Volume (kg) (AxB)	Market Price (USD/kg) (C)	Value (USD)	Total area (ha)	Ave. yield (kg/ha/yr)- see Fig 13	Total volume (kg) (D)	FLW volume (kg) (AxD)	FLW value (USD) (AxDxC)
Cashew (RCN)	28.75	3.28	32.03	2,747	832	1.10	916	334,000	765	255,510,000	81,839,853	90,023,838
Cassava (roots)	20.20	19.30	39.50	37,268	14,721	0.14	2,061	705,450	14,321	10,102,749,450	3,990,586,033	558,682,045
Coconut (nuts)	41.10	14.14	55.24	417	230	0.59	136	29,000	10,759	312,011,000	172,354,876	101,689,377
Corn (kernel)	21.03	3.14	24.17	13,150	3,178	0.14	445	277,000	8,985	2,488,845,000	601,553,837	84,217,537
Pepper (fruit/corm)	ne	4.1-8.3	4.1-8.3	1,450	59.4-120.4	17-30	1,010-3,882	6,935	625	4,334,375	177,709-359,753	3,021,053-10,792,594
Sugarcane (cane)	15.53	5.67	21.20	27,918	5,919	0.42	2,486	30,287	21,608	654,441,496	138,741,597	58,271,471

[1]Harvest loss mainly due to reduced yield

[2]Postharvest loss due to poor handling. Some farmers (10-100% per crop) reported storage loss but no estimate (ne)

RCN-raw cashew nuts

Table 3. Product volume and value of FLW of other value chain actors per year.

Value Chain	Product type	% FLW	Supply (kg)	FLW volume (kg)	Market price (USD/kg)	FLW value (USD)
Cashew - processor	Defective RCN	3-5	200,000-300,000	6,000-15,000	1.10	6,600-16,500
	Low grade RCN	2	48,500-71,2502	970-1,425	1.10	6,600-16,500
Coconut - collector	Defective nuts	3-5	499,200	12,480-24,960	0.59	7,363-14,726
Processor	Copra (dried meat)	13	20,000-30,000	2,516-3,774	2.96	7,447- 11,171
Corn - processor	Defective kernels	2-3.3	1,000,000-1,800,000	20,000-59,400	0.14	2,800-8,316
Pepper - processor	Rejects	4.1-8.3				

Climate impact on FLW

Farmers of the 6 crops experienced climate change manifested as intense rainfall and drought, very hot and unpredictable weather (Table 4). This has affected production as reduced yield, failure to flower and fruit, reduced quality and plant mortality, except in cashew in which only 40% of the farmers acknowledged this. The reduced yield which contributed to harvest loss (Table 2) can therefore be partly attributed to climate change effect. About 80-100% of farmers of the 6 crops conceded that they incurred product loss the past 5 years due to climate change. However, few farmers provided an estimate of discarded/unsold produce which were used at home, as feed or for compost making; sold at low price; and/or thrown away. Some cashew and corn farmers gave an estimate of loss of about 10-100 kg and 250 kg, respectively. This volume of produce was sold at reduced priced that resulted in a loss of 26.6-40.7% for cashew and 1.14% for corn. The insufficiency of data suggests lack of farmers' awareness and appreciation of FLW particularly as affected by a changing climate.

Table 4. Climate change experience of farmers and impact on FLW of 6 crops.

Particulars	Cashew	Cassava	Coconut	Corn	Pepper	Sugarcane
1. Experience in changes in climate (% yes)	80	80	100	100	100	100
2. Nature of climate change (CC)	Intense rainfall and drought; unpredictable weather; very hot	Drought, hotter weather	Drought, hotter weather	Intense rainfall and drought; unpredictable weather; very hot	Drought	Drought, intense rainfall, very hot
3. Effect of CC on production (% yes)	40	80	100	100	100	70
4. Nature of effect of CC on production	Reduced yield; dehydrated apple	Reduced yield; plant death	Reduced yield; no flower/fruit	Reduced yield; plant death; small kernels	Flower fal reduced yie	Reduced yield; crop failure
5. Product loss in past 5 years due to CC (% yes)	80	80	100	100	100	100
6. Unsold/discarded produce due to CC (% yes)	30	0	27	50	0	70
7. Fate of unsold/ discarded produce	Sell at low price	N/A	Home use; throw away; compost	Chicken feed; sell at low price	N/A	Left in field; compost
8. Volume of unsold/ discarded produce (kg)	10-100	N/A	Ne	250	N/A	Ne
9. % loss due to reduced price	26.6-40.7	N/A	Ne	1.14	N/A	Ne

Ne-no estimate; N/A-not applicable

Table 5. GHG emission of FLW of 6 crops at the farm level based on FAO estimate of 3.3-4.4 tons of CO_2 equivalent per ton of food loss).

Crop	Food loss (tons)	GHG emission (tons CO_2 equivalent)	
		3.3	4.4
Cashew	81,840	270,072	360,096
Cassava	3,990,586	13,168,934	17,558,578
Coconut	172,355	568,772	758,362
Corn	601,554	1,985,128	2,646,838
Pepper	178-360	587-1,188	783-1,584
Sugarcane	138,742	457,849	610,465
Total		16,451,341-16,451,942	21,935,122-21,935,923

FLW contributes to global warming and climate change. The global warming potential of food loss based on greenhouse gas (GHG) emission is alarming. For the 6 crops covered in this study, GHG emission of food loss at the farmer level was estimated to range from 16.5-21.9 megatons of carbon dioxide equivalent (Table 5). Thus, reducing food loss and waste is a critical climate change mitigation strategy.

Waste valorization

Large volume of byproducts of the 6 crops is wasted without value addition (Table 6). For cashew, the largest source of waste is at the production stage, where up to **90%** of the cashew fruit biomass (cashew apple) is left to rot on farms or only minimally used as fodder. This represents a major missed opportunity to extract value, particularly given the potential for processing into higher-value products such as syrups, sugars, or fermented beverages. Cashew shells are currently exported at low prices, while other by-products (e.g., testa, low-grade kernels) are relegated to animal feed. Local valorisation of these streams could capture more value domestically.

For coconut, while on-farm waste of whole fruit is relatively low **(≈5%)**, losses rise sharply at the distribution stage, where approximately **83%** of coconuts sold as fresh drink products end up discarded as husks and shells. Although some coconut processing by-products (meal, husks, shells, water) are already reused for animal feed, compost, charcoal, and vinegar, **most of the fresh-market distribution waste remains untapped**. This creates a strong case for valorisation into energy products (e.g., charcoal briquettes) or bio-based materials.

Table 6. Volume of byproducts of farmers and other value chain actors of the 6 crops per year

Value Chain	Byproduct	Waste (kg/ha)	Area (Ha)	Waste (tons)
Farmers				
Cashew	Cashew apple	6,882	334,000	2,298,588
Cassava	Stems and shoots of plants	6,895	705,460	4,864,427
Corn	Stover-stalks, leaves, husk	11,799	277,000	3,268,379
Pepper	Peels, defective seeds, placenta, stalks, other processing byproducts	1,270	6,935	8,805
Sugarcane	Tops, leaves, other parts of plant	7,592	30,287	229,942
Other VC actors	Byproduct	% waste	Supply (tons)	Waste (tons)
Cashew - processor	Nutshell	75	194-285	146-214
	Testa	1	194-285	0.4-1.4

Coconut – processor	Husks	35	20-30	7-10.5
	Water (ripe nuts)	6-16	20-30	.1.2-1.8
	Shells	25	20-30	5-7.5.8
- retailer juice	Green nut husk and shells	83	5.7	4.8
Corn- processor	Cobs	22-40	2,000-3,000	440-1,200
Sugarcane - processor/ wholesaler	Cane rind	1	218-468	24.2-51.9
- vendor juice	Bagasse	13	1.7-3.6	0.2-0.5

Other crops also reveal systemic inefficiencies. Cassava suffers rapid post-harvest deterioration, with stems and peels often discarded or burned, though pulp is occasionally used for feed. Maize/corn generates high volumes of stover and cobs, most of which are underutilized or discarded. Pepper by-products such as stalks, substandard seeds, and quality-degraded pepper remain largely wasted despite niche uses (e.g., tea). Sugarcane, though partially valorised through bagasse and molasses, still generates significant discarded residues at both processing and distribution levels.

Table 4 (Appendix 1) maps potential processing and conversion options for the major by-products identified across the six value chains. For example, cashew apples, which account for nearly 90% of fruit biomass, can be transformed into juice, syrup, or sugar; coconut husks and shells, which represent up to 83% of distribution-stage waste, can be converted into coir products or charcoal; and cassava peels and pulp can be valorised into animal feed or bioethanol. Similar opportunities exist for maize stover and cobs (bioenergy or mushroom substrate), pepper stalks (herbal teas and extracts), and sugarcane bagasse and molasses (bioenergy, paper pulp, fertilizers). Linking these waste streams to proven or emerging technologies provides a concrete pathway for Cambodia to transition from a loss-driven agri-food system to one that systematically reinvests resources, reduces environmental impact, and supports farmer incomes.

F. Recommendations for Valorisation Strategies and Projects

The analysis of food loss and waste (FLW) across six major agricultural value chains highlights both the scale of by-product generation and the underutilisation of resources with strong valorisation potential. While multiple technologies and practices are technically feasible, prioritisation is required to identify interventions that are impactful, achievable, and relevant to Cambodia's current context. Pilot projects were therefore selected using three criteria: (i) the size and significance of the waste stream, (ii) the technical and market feasibility of available valorisation technologies, and (iii) the contribution of proposed solutions to Cambodia's circular economy objectives.

Cashew and coconut emerged as the two value chains most strongly aligned with these criteria. Cashew generates one of the largest waste streams in Cambodia, with up to 90% of the fruit biomass—the cashew apple—discarded each year, equivalent to more than 2.3 million tonnes. Valorisation technologies such as juice, syrup, jam, fermented beverages, and cashew nutshell liquid (CNSL) extraction are well established globally and show clear market potential. Similarly, coconut waste is significant, particularly downstream at retail and vending stages where approximately 83% of the biomass (husks and shells) is discarded. Local enterprises have already demonstrated the feasibility of converting these into compost, coir-based products, and charcoal briquettes, making the sector both scalable and market-ready. Together, cashew and coconut address highly significant waste streams while offering technically viable, market-driven pathways that advance Cambodia's circular economy transition.

By comparison, cassava, corn, pepper, and sugarcane are less suitable for immediate piloting. Cassava residues, while abundant, require capital-intensive facilities for valorisation into biofuels or biogas, limiting near-term feasibility. Corn generates large volumes of stover and cobs, but current domestic demand for advanced applications such as bioplastics and composites remains weak. Pepper produces relatively low waste volumes, making its contribution to national-level circular economy objectives marginal. Sugarcane by-products such as bagasse and molasses are already partly valorised, while further opportunities like biofuel and bioplastic production demand industrial-scale infrastructure beyond the scope of pilot interventions. These value chains remain important for long-term development but do not meet the three criteria as comprehensively as cashew and coconut.

Based on this consideration, three pilot initiatives have been identified (see Table 2):

1. **Cashew Apple Processing for Sugar Production**

Figure 14: Fresh Cashew apple

The cashew value chain generates one of the largest underutilised biomass streams, with cashew apples comprising up to 90% of total fruit weight but currently left to rot or used in limited quantities as cattle feed. Processing cashew apples into sugar and related products represents a promising pathway to valorise this waste. The technology is relatively simple, aligns with growing demand for natural sweeteners, and offers potential for income diversification at both farm and processing levels. Importantly, it directly addresses a significant food loss hotspot while creating a new marketable product that can also substitute import. Cambodia massively imports sugar mainly from Thailand, Vietnam and China. In 2023, Cambodia's imports of raw sugar were valued at $354 million while the imports of more general "sugars & confectioneries" were higher, at $387 million. Cashew apple contains about 10% sugar by weight and therefore, 100 kg of sugar can be extracted from 1 ton of cashew apple. This nearly approximates sugarcane in which 1 ton (1000 kg) of sugarcane can yield about 120 kg of sugar.

2. **Coconut Waste Processing into Charcoal**

Although on-farm coconut losses are relatively low, downstream distribution and retail stages generate significant waste, with around 83% of biomass discarded in the form of husks and shells. These materials can be transformed into charcoal briquettes, offering a renewable energy alternative that reduces reliance on traditional fuelwood and mitigates deforestation pressures. With enterprises like Khmer Green Charcoal already active, the technology is proven, scalable, and economically attractive. This approach both valorises a high-volume waste stream and supports climate and environmental goals by promoting sustainable energy substitutes.

Figure 15: Coconut young and mature

3. Cashew Nutshell Liquid (CNSL) Extraction

Figure 16: Cashew nutshell

Cashew nutshells, which make up about 75% of the raw cashew nut weight, are currently exported at low value or discarded. Yet they contain Cashew Nutshell Liquid (CNSL), a phenolic-rich extract with wide industrial applications in bio-based resins, surface coatings, adhesives, friction materials, and renewable energy products. Establishing small-scale CNSL extraction facilities in cashew-producing provinces like Kampong Thom could transform a major underutilised by-product into a high-value industrial input. The technology is relatively affordable, and global demand for CNSL products is strong. This pilot would not only create additional revenue streams for processors but also strengthen Cambodia's positioning in the regional bioeconomy.

These three proposals embody the principles of Cambodia's emerging circular economy framework. By converting high-volume agricultural by-products into new marketable products, they close material loops and enhance resource efficiency. Collectively, the pilots strengthen climate resilience by reducing greenhouse gas emissions, diversifying farmer income streams, and decreasing pressure on forests through sustainable energy alternatives. At the same time, they generate new livelihood opportunities in rural communities through processing, collection, and distribution activities. Taken together, the pilots illustrate how practical interventions can simultaneously deliver environmental, social, and economic benefits, offering scalable models to inform policy advocacy and broader circular economy strategies in Cambodia.

Table 2: Pilot Selection and Potential Partners

Potential stakeholders	Pilot 1 Cashew (sugar)	Pilot 2 Coconut (Charcoal)	Pilot 3 Cashew (CNSL)
By-production/ Waste	- Farm – Cashew Apple (90% of Cashew Fruit Biomass), about 6.8 tons per hectare per year of farm production.	- Retailers (83% of biomass young coconut husk), about 8.9 tons per hectare per year of farm production.	- Processor – Cashew Nutshell Liquid (CNSL) Extraction
General information	- Name: Dr. Chay Chim. - Address: No. 242, Preah Norodom Blvd., Sangkat Tunle Basac, Khan Chamkarmorn, Phnom Penh. - Contact: +855 12 718 158	- Name: Mr. Ran Sina - Address: Angkor Char Coal, Sangkat Krang Thnung, Khan Sensok, Phnom Penh - Contact: +855 77 777 945	- Business Name: Asia Cashew Alliance (ACA) - Contact Person: Mr. SOPHAL Laikong - Address: National Road 6, Roung Village, Trapeang Russey Commune, Kompong Svay District, Kampong Thom Province. - Contact: +855-93-295-092
Recommendation model of operation for the FL valorisation project	- Collective: Department of Agro-Industry work with the Cashew Farm Community in Kampong Thom want to delve into sugar processing using Cashew Apple.	- Individual: Valorise coconut waste from retailers into charcoal. He is considering expansion of his production by investing in coconut pressing machine.	- Collective/Individual: ○ **Model:** Individual processor–led, with potential expansion to collective cluster model through cooperation with local cashew processors in Kampong Thom and surrounding provinces. ○ **Focus:** Valorisation of cashew nutshell into CNSL as a high-value industrial input for renewable energy applications.
Technical Information	- Business activity: Cashew Farm Community and Department of Agro-Industry - Volume of production: N/A - Area of interest for piloting: Kampong Thom - Type of food loss/waste for piloting: Valorisation of Cashew Apple into Sugar - Volume FL/FW has per day/time:N/A - Estimated cost of investment on FL/FW technology: 5-10k USD - Willingness in cost sharing: N/A	- Business activity: Charcoal Production - Volume of production: 8 tons/day - Area of interest for piloting: Phnom Penh - Type of food loss/waste for piloting: Valorise Coconut husk (waste) into charcoal. Coconut waste from fresh coconut retailers. - Volume FL/FW has per day/time: 10 tons/day - Estimated cost of investment on FL/FW technology: 5-10K USD - Willingness in cost sharing: 50%	- Business activity: Cashew nutshell collection and processing into Cashew Nutshell Liquid (CNSL) - Volume of production: Pilot capacity of 8–10 tons of cashew shells per day, expected to yield 1,200–1,500 kg of CNSL/day - Area of interest for piloting: Kampong Thom Province. - Type of food loss/waste for piloting: Valorisation of cashew nutshell (by-product of kernel processing) into CNSL. - Volume FL/FW has per day/time: Each medium-scale processing plant generates 5–10 tons/day of shells from local processors in Kampong Thom Province and nearby provinces (equivalent to 1,500–3,000 tons/year in pilot areas. - Estimated cost of investment on FL/FW technology: Approx. **USD 10,000–15,000** for a small-scale CNSL extraction unit (mechanical press + filtration + storage) - Willingness in cost sharing: 50% (in partnership with donor programs)

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H. Appendices

Appendix 1. Supporting Tables

Table 3: Summary of Crop by-products and their current utilization at different stage in Cambodia

Pepper	Cashew	Cassava
Production • Stalks & other byproducts (≈67%) – some used for tea, mostly left to rot. • Damaged/substandard seeds (5–10%) – sold as low-grade pepper to middlemen. • Remaining byproducts – generally discarded at farms. **Trading** • No major waste/byproducts identified. **Processing** • Substandard/damaged pepper (5–10% of purchased quantity) – sorted out and sold at lower price (USD 3–5/kg). • Post-harvest storage loss (12 months): - Essential oil degradation – 22% - Piperine degradation – 19% - Color loss – 31% **Distribution** • Not reported.	**Production** • Cashew apple (≈90%) – mostly left to rot on farms; sometimes used as cow fodder. **Trading** • No major byproduct/waste recorded. **Processing** • Defected RCN (3–5%) – sold cheaply to Vietnam (USD 300–500/tonne). • Shells (6–7% of fruit / ~75% of RCN) – exported to Vietnam for valorisation (USD 50–70/tonne). • CNSL in shell (1.5–2.5% of fruit / 18% of shell) – extracted and sold. • Testa (0.2–0.5% of RCN) – sold to feed producers. • Low-grade kernels (≈2%) – mixed with testa and used in animal feed. **Distribution** • Not reported.	**Production** • Stems/shoots (32.5%) – some reused for replanting, most left to decay. **Trading** • No major waste/byproducts identified. **Processing** • Peels (10.6%) – discarded. • Residual pulp (6.7–10.1%) – used as animal feed. **Distribution** • Not reported.
Coconut	**Corn/Maize**	**Sugarcane**
Production • Defected/damaged coconuts (≈5%) – consumed if usable; otherwise left to rot. **Trading** • Damaged coconuts (2.5–5%) – from transport/handling; usually discarded. **Processing** • Husks (≈35% of mature nut biomass) – used in compost and as growing medium. • Meal (≈33.8% of mature nut biomass) – fermented with molasses, used for animal feed.	**Production** • Defected kernels (1.6–4%) – some used as animal feed; others discarded. • Stover (stalks, leaves, husk ≈56.8%) – mostly left in field and burned. **Trading** • No major byproduct noted. **Processing** • Corn cobs (≈8.5%) – traditionally used for mushroom substrate or as fuel; now often discarded due to declining demand.	**Production** • Tops, leaves, other plant parts (≈26%) – mostly left on farm and burned. **Trading** • No byproducts noted. **Processing** • Bagasse (≈23.7%) – sold to paper plate manufacturers. • Molasses (≈4.2%) – sold for fertilizer production. • Rind (≈11.1%) – discarded or given as cattle feed. **Distribution**

• Coconut water (6.5–16.25% of mature nut biomass) – used to make coconut vinegar. • Shells (≈24.7% of mature nut biomass) – sold for charcoal production. **Distribution** • Green coconut husks & shells (≈83% of supply) – disposed of in waste piles.	• Broken/low-quality kernels (0.4–0.6%) – sometimes used as fodder for cattle/poultry. **Distribution** • Not reported.	• Juice vendors: Bagasse (≈12.6%) – disposed of in garbage piles.

Table 4 Summary on literature review of Valorisation Technology or activities.

Literature Review on Valorisation Technology or Activities
Pepper Black pepper processing often releases large amounts of by-products into the environment including leaves, flattened seeds, and seed-bearing branches. These by products have been used to extract essential oil which are shown to have antibacterial capacities (Phan, 2023). Studies have shown that by-products or damaged black pepper can be reclaimed and used for the extraction of piperine alkaloid for pharmaceutical uses (Lwamba, 2023). The average moisture content (MC) of peppercorn ranges from 70% to 85%. The average MC of dried peppercorn should be around 8.7% - 14%. Source: Phan, H. T. (2023). Optimization of essential oil extraction process from Piper nigrum L. by-products and investigation of its biological activities. *The Journal of Agriculture and Development, Nong Lam University*, Volume 22- Issues 6. Lwamba, C. (2023). Innovative Green Approach for Extraction of Piperine from Black Pepper Based on Response Surface Methodology. *Sustain. Chem*, 40-53; https://doi.org/10.3390/suschem4010005.
Cashew nut kernels, the main economic product of cashew, are highly nutritious, containing about 21% protein, 23% carbohydrates, and 46% fats, of which 80% are unsaturated helping reduce cholesterol levels. **Cashew** Cashew byproduct valorisation offers diverse value-added opportunities (David, 2015; Kyei, 2023): ▪ Cashew apples: Beyond animal feed, they can be processed into juices, syrups, wines, jams, alcoholic beverages, and dietary fiber extracts. Cashew apple juice also serves as a medium for microbial cultivation, producing compounds like dextran and lactic acid. The fibrous cashew apple bagasse left after juice extraction is rich in nutrients, fiber, bioactive compounds, and vitamin C, with uses as animal feed, nutritional supplements, functional foods, and sources of natural preservatives and nutraceuticals. ▪ Cashew nut shells (CNS): Useful for bioenergy (biogas), water purification (adsorbents for heavy metals and pollutants), and as fillers in biocomposites. ▪ Cashew nutshell liquid (CNSL): A phenolic-rich extract (anacardic acid, cardol, cardanol) applied in dyes, friction linings (e.g., brake pads), surface coatings, adhesives, varnishes, and pharmaceuticals. Source: Kyei, S. K. (2023). A comprehensive review on waste valorization of cashew nutshell liquid: Sustainable development and industrial applications. Cleaner Waste Systems, https://www.researchgate.net/ publication/373096614 A_comprehensive_review_on_ waste_valorization_of_cashew_nutshell_liquid_ Sustainable_development_and_industrial_ applications David, C. a. (2015). Value Added Products from Cashew Apple. Acta Horticulturae, 1080,, 383-389. https://doi.org/10.17660/actahortic.2015.1080.51.

Cassava

Cassava byproducts—peels, leaves, fibrous waste, and wastewater—can be transformed into diverse value-added products (Nizzy, 2022; Aduba, 2023; Awogbemi, 2024). Peels, which make up 10–20% of cassava's fresh weight, and other residues offer multiple uses:

- Biochar: Pyrolyzed cassava peels yield carbon-rich biochar that improves soil fertility, water retention, and nutrient availability, while also sequestering carbon and reducing the need for chemical fertilizers.
- Biofuels: Wastewater from starch extraction, along with leaves and fibrous waste, can be converted into ethanol, biogas, biobutanol, and biohydrogen through fermentation and anaerobic digestion.
- Organic fertilizers: Peels and leaves can be composted to enrich soil and improve yields.
- Other products: Wastewater can produce eco-friendly biosurfactants, cassava starch can be used for bioplastics, and wastes can generate antimicrobial agents, adsorbents for wastewater treatment, and D-lactic acid, a building block for biodegradable polymers.

Source:

Nizzy, A. K. (2022). A review on the conversion of cassava wastes into value-added products towards a sustainable environment. Environmental Science and Pollution Research, Volume 29, pages 69223–69240 ; https://link.springer.com/article/10.1007/s11356-022-22500-3

Aduba, C. C. (2023). Integrated Valorization of Cassava Wastes for Production of Bioelectricity, Biogas and Biofertilizer. Waste and Biomass Valorization, Volume 14, pages 4003–4019; https://link.springer.com/article/10.1007/s12649-023-02126-3.

Awogbemi, O. (2024). Transformation of Cassava Wastes into Useful Products. In J. J. Arora, Transforming Agriculture Residues for Sustainable Development. Waste as a Resource (pp. pp 353–370). Springer, Cham.

Coconut

A coconut consists of about 35% husk, 24.7% shell, 33.8% meat and testa, and 6.5–16.25% water. All parts can be valorized, supporting a circular economy and resource efficiency. (Singh et al., 2024; Vieira et al., 2024; D'Almeida & de Albuquerque, 2025)

- Shell: Used for biochar (soil fertility, water retention, carbon sequestration), porous carbon, bio-additives for epoxy resins, and thermal energy generation.
- Husk (mesocarp): Source of coir for mats, ropes, and geotextiles; also used for bioethanol, paper, pulp, insulation materials, biosorbents, ethanol production, and biocomposites.
- Water: Processed into food, beverages, and fermented products.
- Other applications: Coconut wastes can become cementitious materials, bio-adsorbents for water treatment, and alternative solid fuels.

Coconut residues are mainly composed of cellulose, hemicellulose, and lignin, giving them broad potential for industrial, agricultural, and environmental uses.

Source:

Singh, P., Dubey, P., Younis, K. et al. 2024. A review on the valorization of coconut shell waste. Biomass Conversion and Biorefinery 14: 8115–8125. https://doi.org/10.1007/s13399-022-03001-2

Vieira, F., Santana, H.E., Jesus, M., Santos, J., Pires, P., Vaz-Velho, M., Silva, D.P. and Ruzene, D.S. 2024. Coconut Waste: Discovering Sustainable Approaches to Advance a Circular Economy. Sustainability 2024, 16, 3066. https://doi.org/10.3390/su16073066

D'Almeida, A.P. and de Albuquerque, T.L. 2025. Coconut husk valorization: innovations in bioproducts and environmental sustainability. Biomass Conversion and Biorefinery 15: 13015-13035. https://doi.org/10.1007/s13399-024-06080-5

Corn

Corn wastes—husks, cobs, straw, and other byproducts—can be transformed into food, feed, construction materials, biofuels, batteries, biodegradable packaging, adhesives, and other sustainable products (Castrillon et al., 2021; Ratna et al., 2022; Souza, 2023; Phiri et al., 2024).

- Husks: Used in papermaking, bioplastics, composites, and reinforced materials with properties like heat resistance, sound absorption, and flame resistance.

- Cobs: Applied in construction (e.g., corn-wall), as absorbents, and in biomass-based composites. Corn-wall is produced by grinding dried cobs, pressing with heat, and coating with bio-based waterproofing for durability.
- Straw: Utilized in papermaking, packaging, and composites.
- All residues: Convertible into biochar via pyrolysis; also sources of bio-based adhesives, low-cost sugars for biofuel, and substitutes for petroleum-based plastics in batteries.

Corn husk and cob receive special attention due to their abundance, low cost, and biodegradability.

Source:

Castrillon, H.D., Aguilar, C.M. and Álvarez, B.E. 2021. Circular Economy Strategies: Use of Corn Waste to Develop Biomaterials. Sustainability 13: 8356. https://doi.org/10.3390/su13158356

Ratna, A.S., Ghosh, A. and Mukhopadhyay, S. 2022. Advances and prospects of corn husk as a sustainable material in composites and other technical applications. Journal of Cleaner Production 371: 133563. https://doi.org/10.1016/j.jclepro.2022.133563

Souza, S. 2023. Turning corn waste into an innovative bio-based material. https://www.archdaily.com/1010712/turning-corn-waste-into-an-innovative-bio-based-material-cornwall-r

Phiri, R., Rangappa, S.M. and Siengchin, S. 2024. Agro-waste for renewable and sustainable green production: A review. Journal of Cleaner Production 434: 139989. https://doi.org/10.1016/j.jclepro.2023.139989

Sugarcane

Sugarcane harvesting and processing generate several byproducts—tops, bagasse, press mud, and molasses—all with significant valorisation potential (Singh et al., 2021; Poria et al., 2022; Ungureanu et al., 2022; Ding, 2024; Matsueda & Antunes, 2024).

- Sugarcane tops (leaves and cane remnants) can be used for biofuels (bioethanol, biogas, bio-oil, biochar), heat and electricity generation, animal feed, and as a raw material for bioplastics.
- Bagasse (30–40% of cane weight) is used in biobased materials, fodder, pollutant adsorption, and thermal energy production.
- Press mud (filter mud) is nutrient-rich and applied as fertilizer, soil conditioner, or bio-compost; it can also serve as animal feed, biofuel, wax, and in cement or soil remediation.

Molasses is a key substrate for fermentation into ethanol, butanol, and lactic acid, and is also used in livestock feed, bio-based polymers, adhesives, construction materials, food, pharmaceuticals, and as a feedstock for biochar catalysts.

Source:

Singh, S.P., Jawaid, M., Chandrasekar, M., Senthilkumar, K., Yadav, B., Saba, N. and Siengchin, S. 2021. Sugarcane wastes into commercial products: Processing methods, production optimization and challenges. Journal of Cleaner Production 328: 129453. https://doi.org/10.1016/j.jclepro.2021.129453

Poria, V., Jhilta, P., Rana, A., Khokhar, J. and Singh, S. 2022. Pressmud: a sustainable source of value-added products. Environmental Technology Reviews 11(1): 187-201. https://doi.org/10.1080/21622515.2022.2144767

Ungureanu, N., Vladuț, V. and Biriș, S.Ș. 2022. Sustainable Valorization of Waste and By-Products from Sugarcane Processing. Sustainability 14: 11089. https://doi.org/10.3390/su141711089

Ding D.Y. 2024. Valorization of sugarcane by-products from waste to wealth. Journal of Energy Bioscience 15(1): 20-27. doi: 10.5376/jeb.2024.15.0003

Matsueda, Y. and Antunes, E. 2024. A review of current technologies for the sustainable valorisation of sugarcane bagasse. Journal of Environmental Chemical Engineering 12 (6): 114900. https://doi.org/10.1016/j.jece.2024.114900

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