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REVIEW

Why does food loss and waste matter for food security - from the perspective of cause and magnitude

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Abstract – Food security has raised crisis alarms all over the world. Especially nowadays, conventional agriculture is threatened by climate change and extreme weather, and the agri-food system is loading the increasing population burden. Food loss and waste (FLW) have gotten more and more attention. Still, the main research focus is on a narrowed and specific stage of the food value chain of specific food types in a particular area, which lacks an overall comprehensive understanding of this topic from a broad view. This review aims to provide a comprehensive description of food loss and waste and provide a useful theoretical background to public decision-makers and individuals to reduce food loss and waste for a better and more sustainable society, economy, and environment. Secondary research and content analysis are used in this review as methodology, following Michael E. Porter's value chain theory, to analyze and simplify the sustainable path (in light of the cause and magnitude of food security based on the nexus between food security and food loss and waste across the entire food value chain (from the main manifestation of FLW: agricultural production stages, such as cultivation or breeding and storage, post-harvest processing and distribution, and retail and consumption. We also provided the Ishikawa model diagram to better explain the causes of food loss and waste. And other manifestations, such as the COVID-19 and Russia and Ukraine war). To conclude, reducing food loss and waste is crucial for sustainable food security, but the manifestation of FLW differ in different stage of the value chain and different food types. Generally speaking, production sees the most loss, while consumption sees the most waste. Therefore, we suggest both public and private should be aware that producing more food and utilizing food resources properly along different stages of the value chain is equally important.

Keywords – Food loss, Food waste, Food security, Sustainability, Supply chain, Value chain

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INTRODUCTION

The essential elements for human living are water, air, and food. It is challenging to fulfill the food demand of the growing population (estimated to increase to 9.1 billion in 2050) with limited resources. Additionally, agricultural production has been negatively impacted by abrupt climate change brought on by carbon emissions from the combustion of fossil fuels in many parts of the world (Abbas et al., 2022a; Elahi et al., 2022; "How to feed the world 2050," n.d.). Agriculture and food are broad topics involving various fields, such as biology, marketing, geography, technology, etc. For example, plant diseases, soil conditions and the way of technologies used in fields can directly influence on the yields. The imbalance of food market demand and supply can result in food loss and waste. Regarding food, hotspots such as food safety and food security are mentioned, which interpenetrate. Either food safety or food security cannot exist without the other. Food safety refers to the food taken by humans is safe, not harmful, and not contaminated, but it is not our focus in this research. Food security mentions food availability in a rough view. In this research, we only focus on food security and seek a sustainable path in light of food loss and waste.

Besides these unpredicted human catastrophes, such as the COVID-19 pandemic and war in Ukraine, there are some consistent threats and risks in agriculture and food. For example, chronic climate change or extreme weather (threaten agriculture through their influence on ecology, the environment, the geographical situation of crop and crop production, the resources and supply chain of agriculture, and the market price) (Agrimonti et al., 2021; "Food Security Concepts and Frameworks," 2008; "Sustainable and Digital Agriculture | United Nations Development Programme," n.d.), natural resources scarcity (arable lands and water) ("Challenges for modern agriculture," n.d.; "Sustainable and Digital Agriculture | United Nations Development Programme," n.d.), agriculture facilities issues (aging farmers and fewer farmers because of urbanization) ("Challenges for modern agriculture," n.d.; "Digital Agricultural Academy of Hungary to take farmers into a new age," n.d.; Somosi and Számfira, n.d.), food market fluctuation (FAO publications catalogue 2022, 2022). Pursuing a sustainable path of food security is not only a feasible solution but also an emergent path for our present and future generations.

Food loss and waste is a problem that affects the entire world. The United Nations declared November 29 as the International Day of Awareness of Food Loss and Waste (IDAFLW) in 2019. The day aims to encourage public and private sectors to work together to reduce food loss and waste (Nations, n.d.). Food waste burdens society (food insecurity), the environment, and the economy. Energy and land use across the food value chain is wasted from wasted food, and the energy from food is lost across the food value chain. Still, the landfill can be reduced, and energy can be generated from wasted food utilization (Ghosh et al., 2015). FAO reported that lost and wasted food can feed around 1.26 billion people yearly ("Tackling food loss and waste," 2022).

Food loss and waste is approximately 14% yearly, valued at $400 billion after harvest and before market. And 17% or 931 million tonnes of food is lost between market and consumption, such as households, restaurants, retailers, households, and other food service types, especially households (11% in households, 5% in the food service, and 2% in retail) (FAO, 2021; "Food loss and waste," n.d.; "International Day Food Loss and Waste| Technical Platform on the Measurement and Reduction of Food Loss and Waste | Food and Agriculture Organization of the United Nations," 2022; "Tackling food loss and waste," 2022; Nations, n.d.). And 8-10 percent of global greenhouse gas emissions (GHGs) are from food loss and waste, which worsen the unstable climate and extreme weather. Vice versa, the more unstable climate change and extreme weather negatively impact crop production and crop yields ("International Day Food Loss and Waste| Technical Platform on the Measurement and Reduction of Food Loss and Waste | Food and Agriculture Organization of the United Nations," 2022; "Tackling food loss and waste," 2022). The greenhouse gas emission of food loss and waste ranks after China and the US if we regard it as a country. And the ranking source of greenhouse gas emissions is the construction, transport, and food industries (Bori, 2018; Environment, 2021; Papargyropoulou et al., 2014).

Eighty-eight million tonnes of food waste (approximately 20% (Łaba et al., 2022)) is generated annually (Bori, 2018), and 10% of it is because of the date marking on food products ("'Use by' or 'best before'? |Food Loss Reduction CoP| Food and Agriculture Organization of the United Nations," n.d.) in the European Union Food waste is a long-lasting issue in some countries. According to the official report or data of Hungary, the food waste is more than 300,000 tonnes every year, equal to over 170 billion forints (EUR 480m) and 18,000 HUF per person ("Over 300,000 tonnes of Food Wasted in Hungary Annually," 2020). In 2016, the food waste was 68.04 kg per capita annually, and 48.7% of total food waste equals 33.14 kg/per capita/year could be avoidable (Szabó et al., 2018). In 2019, the food waste was 65.49 kg per capita annually, and 48.81% of it could have been avoided (Kasza et al., 2020). In 2020, the annual food waste was up to 68 Kg per person, and 31.97% was avoidable ("Annual Food Waste In Hungary Amounts To 68 Kg Per Person," 2020; "Hungary," n.d.). The avoidable food waste percentage in 2016, 2019, and 2020 is 48.7%, 48.81%, and 31.97%, respectively, in Hungary, which means that it is possible to reduce food waste by some measures. There is still potential to reduce avoidable food waste in Hungary. In a four-month study about food waste generation (images were taken before and after meals every day), between 20-30 years old people in Serbia in 2022 estimated that food waste was about 21.3% (Lubura et al., 2022). The wheat-based food loss and waste were estimated at 36% or 4 million tons per year in Morocco (Bartali et al., 2022). University canteens play an essential role in students' food consumption outside of the home (Lachat et al., 2009). The survey in a Portuguese university with 7,000 students for ten days observation of canteen food waste has estimated that the monthly food waste could be 417 kg and economic loss would be 3080 euros (Martinho et al., 2022). Food loss and waste are not just recent year issues; they also existed for decades. For example, in New Zealand, where food waste is less than in other countries, the annual food waste is up to 131 USD per person, 163*109 calories, and avoidable food waste can feed from 50,000 to 80,000 people yearly.

It was estimated that in 2001, 4.2 million tonnes of greenhouse gas metrics CO_2 equivalents (55% is from household food waste, and 45% is from industry) (Reynolds et al., 2016). It was estimated that the wasted annual consumer cereals could produce 0.608 million tonnes of CO_2, according to the data between 2017 and 2018 (Łaba et al., 2022). Food loss and waste is a highly debated topic and suggested to pay attention in the next decades as food loss, and waste have an intense impact (Xie et al., 2021) on food security (Bori, 2018; Gustavsson et al., n.d., p. 201). The food loss and waste policy is suggested as the primary driver of food security and the second most recommended policy after food security (Wahbeh et al., 2022).

Reducing food waste is one solution for ensuring food security (Bartali et al., 2022; Xie et al., 2021). Food security was first defined in the 1970s and improved to a more accurate and acceptable concept by FAO, World Bank, and World Food Summit. It mainly refers to four aspects (FAO, 2006):

- Food availability means an adequate food supply with proper, safe food.
- Food access promises everyone to access sufficient and nutritional food at the individual, regional, or national levels.
- Utilization refers to the food supplied to all people to meet nutritional requirements.
- Food stability requires availability and access for all people, even in the shock of economic crises, climate crises, or seasonal food insecurity.

Food loss and waste have been given attention to by global focus. The 2030 Agenda for Sustainable Development was released by 193 United Nations members in 2015, which adopted 17 sustainable development goals to end poverty in 2030 ("193 Member States Archives," n.d.; Neshovski, n.d.). Economic, social, and environmental sustainability are the three main dimensions of the 17 SDGs. Food loss and waste are also highlighted among the 17 SDGs, such as Goal 2 (End Hunger) and Goal 12.3, "By 2030, half per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses" under the Goal 12 "Ensure sustainable consumption and production patterns" ("A/RES/70/1 Transforming our world: the 2030 Agenda for Sustainable Development," 2030; "Food waste reduction | Community of Practice on food loss reduction (CoP) | Food and Agriculture Organization of the United Nations | Food Loss Reduction CoP | Food and Agriculture Organization of the United Nations," n.d.). Food security is a broad and complicated problem ("Food Security Concepts and Frameworks," 2008). Food loss and waste occur across the whole food value chain but vary widely from the food sector and stage of the food value chain. The future of tackling food loss and waste is not just for ensuring food security but also for adapting to climate change and pursuing sustainability ("Tackling food loss and waste," 2022).

However, the current research about food loss and waste mainly focuses on a narrowed and specific stage of the food value chain in a particular area, which needs a comprehensive understanding of this topic from a broad view. For example, Fernandez et al. (2020) only provided the mass economic losses of Spanish persimmon at primary production and the reduction measurements. Redlingshöfer et al. (Redlingshöfer et al. 2017) only discussed the cause, food loss, and waste management upstream of the food supply chain, including primary production and processing in France. Łaba et al. answered the same question on consumer cereals in Poland (Łaba et al., 2022). Owino and Ambuko concluded the processing trends of mango fruit processing during the post-harvest stage due to post-harvest loss in developing countries (Owino and Ambuko, 2021). Goldmann et al. provided the cause, magnitude, and solutions of food loss in Poland's bakery and confectionery industry (Goldmann et al., 2021). Kamda et al. (Kamda et al., 2021) surveyed the causes and solutions of fresh fruits in the post-harvest stage in Cameroon. Buzby et al. (Buzby et al., 2015) investigated the cause of fresh fruit and vegetables at a retailer (supermarkets) and provided possible solutions to reduce fresh produce loss in the US.

Therefore, this research aims to provide a comprehensive study to simplify the sustainable path of food security based on the nexus between food security and food loss and waste. Besides, our research comprehensively understood food loss and waste across the agri-food value chain. The aim is to analyze the cause and manifestation of food loss and waste at all stages of the food value chain, and the Ishikawa model diagram of causes of food loss and waste is provided at the end of the article. The motivation for undertaking this comprehensive research is to provide useful information and directions for government, producers, public organizations or businesses, and private individuals to take action and develop practices on minimizing food loss and waste for the benefit of society, the environment, and the economy.

MATERIALS AND METHODS

We used literature review (Garza, 2015) and content analysis (Stemler, n.d.) as the research method, which helped to bridge the research and studies gap to identify the cause and magnitude of food loss and waste. The literature and data are from prestigious journals (Critical Reviews in Food Science and Nutrition, Sustainability, Food Chemistry), global organizations (The United Nations FAO), etc. To comprehensively understand the food system and determine the food loss and waste, we analyzed the reason and magnitude based on Michael E. Porter's value chain theory (Porter, 1985). Michael E. Porter's value chain theory is defined as "Describing the full chain of a business's activities in the creation of a product or service from the initial reception of materials through its delivery to market, and everything in between," and it contains two main logic, five primary activities (inbound logistics, operations, outbound logistics, marketing, and sales, and services) and four supporting activities (technology development, procurement, immutable infrastructure, and human resources). In the end, we summarized the causes of FLW by the Ishikawa model (Hayes, 2023), which better explains the main causes of FLW in the whole value chain.

RESULTS

Nevertheless, nowadays and a decade ago (Ghosh et al., 2015), food loss and waste is a severe global issue that needs urgent global solutions across the food value chain to ensure sustainable food security, economy, and environment for the present and future generations. However, food loss and waste are not distributed equally in the supply chain steps (Bhattacharya et al., 2021) and are not the same in all countries. In this research, we followed the food value chain from primary agricultural production (including storage), post-harvest production (including storage, industrial

processing, and distribution), and consumption to investigate the cause, magnitude, and measurements of food loss and waste in the mentioned stages and ensure food security. The results of our review are shown by the structure: firstly, we summarised the cause and magnitude of food loss and waste in different countries. After understanding the cause and magnitude of food loss and waste, we researched the possible sustainable paths and solutions to deal with food loss and waste, which ensure sustainable food security.

As we discussed above, food loss and waste influence food security and safety, food quality, and sustainability. The impact of food loss and waste can be seen from three dimensions: society, environment, and economics. Łaba et al. (Łaba et al., 2022) also argued that food loss and waste are ethical problems. The more detailed impacts can be concluded as the emissions of greenhouse gases, waste, and loss of calories. Besides, the loss of energy (caused by food production and processing across the food value chain and the energy captured in wasted food), land use (the wasted food's destination is to be buried in landfills), and water (Łaba et al., 2022) are also the impact of food loss and waste (Ghosh et al., 2015). In this part, we focused on the manifestation of food loss and waste across the food value chain to discover the cause and magnitude of food loss and waste. The relevant literature is summarised in Table 1.

Table 1. Summary of literature about the manifestation of FLW along FSC

The main manifestation of FLW along FSC in different countries	Reference
Agricultural production stage (cultivation/breeding and storage)	Łaba et al., 2022; "Food waste reduction | Community of Practice on food loss reduction (CoP) | Food and Ag-riculture Organization of the United Nations | Food Loss Reduction CoP | Food and Agriculture Organization of the United Nations," n.d. ; ("Food Surplus," n.d. ; ("'Why SURPLUS food is important' #WorldEnvironmentDay special," 2017
Post-harvest processing (processing and distribution)	Redlingshöfer et al., 2017; Owino and Ambuko, 2021; Goryńska-Goldmann et al., 2021; Porter, 1985; "Food logistics," 2022; ("FAO - story: Improved supply chain management and logistics," 2019
Retail and consumption	FAO, 2021; Nations, n.d; "Tackling food loss and waste," 2022; Peter Bori, 2018; Goryńska-Goldmann et al., 2021; Garza-Reyes, 2015

Source: own construction

1. AGRICULTURAL PRODUCTION STAGE (CULTIVATION/BREEDING AND STORAGE)

Agriculture depends on weather conditions (Fernandez et al., 2020). Therefore, food loss at primary production is very vulnerable to weather conditions. Pest damage, harvest handling, the demand of the market, and agricultural techniques and facilities are also the main factors contributing to food loss at primary production. Cereal is one of the basic agricultural activity directions and the most crucial crop group economically. Cereal grain is regarded as an essential raw material of food and feed materials (Łaba et al., 2022). Cereals and cereal products (30.4%) are among the six significant Polish diet nutrients (Laskowski et al., 2019).

Nevertheless, cereal security plays a vital role in Polish food security. Poland plays an essential role in the EU as the third producer of cereal products (SA, n.d.). Primary production

is also defined as "the production, rearing, or growing of primary products including harvesting, milking and farmed animal production before slaughter, and it is also included hunting and fishing and the harvesting of wild products" ("General Provisions | Game | Food Legislation | Legislation | The Food Safety Authority of Ireland," n.d.). Most of the negative environmental impact of food loss and waste occurs at the primary production stage (Scherhaufer et al., 2018). The food waste at primary production accounts for 53.4% of the total loss, with 117.24 thousand tonnes in Poland in 2017-2018.

In our research, we take the suggestion from Łaba et al. (Łaba et al., 2022) to identify the scale of primary production, starting from the ripe of cereal (including cultivation) and ending at entering the processing stage. According to the first comprehensive research conducted in 2019 in Poland, which was guided by the recommendations of the EC in delegated decision 2019/1597 (COMMISSION DELEGATED DECISION (EU) …/… supplementing Directive 2008/98/EC of the European Parliament and of the Council as regards a common methodology and minimum quality requirements for the uniform measurement of levels of food waste, 201AD), on the scale of loss and waste of consumer cereals (wheat, rye, barley, oats, and maize) at the primary production stage, the annual mass balance production (between 2014-2018) of wheat, rye, barley, oats, and maize are respectively 10980, 2369, 3304, 1352, 3971 thousand tonnes, and the average losses are 158.1, 33.2, 5.3, 0.5, 1.6 thousand tonnes in the same analyzed period (Łaba et al., 2022). It was calculated that 219.6 thousand tonnes of cereal are lost per year at primary production, and the percentage of total consumer cereal production was 1.7% in 2017-2018.

The grain losses occurred at the primary production, including the transport from the field to where it will be sold as raw materials or processed post-harvest treatments and storage. The highest grain loss is wheat and rye. The grain losses differ from the type of cereal, the volume of production, and the food purpose. The storage on farms (primary cause: moisture, grain damage, and pest outbreaks, less frequent cause: overgrowth, mouldiness, change in grain odor or occurrence of fire in the warehouse), the unsuccessful delivery because of the inadequate quality of raw materials and transport respectively accounts for 80.5%, 11.5%, 8% of the grain losses.

2. POST-HARVEST PROCESSING (PROCESSING AND DISTRIBUTION)

According to the food value chain, raw materials or primary product goes to the next step: post-harvest processing, including processing and distribution missions.

Food loss and waste in the processing stage generate the minimum food waste of total production and among the other food value chain stages (Goldmann et al., 2021), but not for all food categories. For example, mango is one of the major tropical fruits globally and one of the most important potential fruits for food processing (FAO, n.d.). The post-harvest loss of mango is among 30-80% (harvesting, packing, and distribution) in some developing countries (Maloba et al., 2017; Sheahan and Barrett, 2017).

There is potential for economic development from the view of food processing enterprises (micro, small, medium, and scale). The challenges from the supply chain result in the food loss problem during post-harvest processing, especially in developing countries. The challenges from the food supply chain are from the capacity of enterprises themselves and other eternal causes (Goldmann et al., 2021; Kamda Silapeux et al., 2021; Owino and Ambuko, 2021):

- **Human error:** Food loss is a natural phenomenon due to food processing involving human operations. This error can be naturally unintentional operation routine or insufficient qualifications.
- **Inadequate infrastructure:** the poor road conditions for processed food or raw materials distribution raise the cost. Transport is where Poland's highest bakery and confectionery industry food loss happened. Transport is also the cause of mechanical damage to the fruit. The storage conditions of a warehouse (temperature, humidity, light, and so on) and measurements against pest harm are also key points resulting in food loss and waste during post-harvest processing.
- **Immature food processing sector:** especially in some developing countries, the food processing sector is still in an informal status, increasing the cost of processed food products.
- **Incompleted laws and regulations:** the related laws and regulations to the food processing sector have duplicity and overlap issues.
- **Immature market environment:** particularly in some rural areas, the processed food products market is confined.
- **High cost of food processing:** FAO defined food processing as "(1) the preservation of foods by (a) modern methods such as refrigeration, canning, and irradiation, and (b) traditional methods such as drying, salting, smoking, and fermentation; (2) the development of protein-rich foods; (3) food additives." ("Food Processing and Preservation," n.d.). The cost of food processing is expensive. And the food processing enterprises also need to afford the expensive energy cost, credit, and taxation.

3. RETAIL AND CONSUMPTION

The management effect of post-harvest food products differs from the knowledge level of retailers, which results in different shelf-life of food products, further different levels of food loss and waste. Retailers who lack knowledge of post-harvest handling and instead rely on years of experience could account for a huge waste of fruit. For example, retailers' different education and training levels in managing fruits result in different ways of transport (transport time, temperature, vehicle, loading feature, packaging materials) (Kamda et al., 2021), improper packaging, and storage (light, cool or cold storage) (Mena et

al., 2011). Some promotions provided by retailers can also cause food waste (e.g., buy one and get one for free). Besides mechanical injury of fruits, damage of equipment and malfunction, negligence of product shelf-life, and spoilage (an increase of ethylene, high metabolic, rodent control, continuous care, hygiene control from dust, bacteria, virus, parasites, and so on) causes are also influencing on shelf-life or products in retail. Inefficient communication between food processing industries or companies and retailers or insufficient prediction information on buyers'/consumers' demands may result in food loss and waste due to unbalanced demand and supply.

According to the estimation from the European Commission, 10% of the annual food waste (88 million tonnes) in the EU results from consumers' misunderstanding of date marking on food products ("'Use by' or 'best before'? |Food Loss Reduction CoP| Food and Agriculture Organization of the United Nations," n.d.). Food products that are close to or beyond „Best Before Date" and „Best Quality Before Date" are usually discarded by retailers and consumers ("Tackling food loss and waste," 2022). Date labeling is criminal to consumers' misunderstanding, and here we listed the main confusing date labeling characteristics: Use by Date or Expiration Date and Best Before Date or Best Quality Before Date (Table 2). Besides the date labeling misunderstanding, household waste is also very harmful and accounts for a big weight of food waste at the consumption stage (FAO, 2021; Nations, n.d.; "Tackling food loss and waste," 2022). Huge amounts of wholesome edible food are left over or not used and discarded in households and eating establishments.

Table 2. The two confusing date labeling explanations of food products

Date labeling	Preference	Feature
Use by Date or Expiration Date	Food safety	Food can be eaten until this date but not after any storage condition due to safety and quality reasons, even if they look and smell fine.
Best Before Date or Best Quality Before Date	Food quality of the unopened shelf-stable product	Food will be safe to eat after this date but may not be at its best. For example, its flavor and texture, freshness, taste, aroma, or nutrients might not be as good.

Source: own construction

4. OTHER MANIFESTATIONS OF FLW

Besides the main manifestation of FLW(across the food supply chain), there are also some other important causes of food loss and waste, such as the impact of the COVID-19 pandemic and the ongoing war ("Russia-Ukraine war: List of key events, day 358 | Russia-Ukraine war News | Al Jazeera," n.d.) between Russia and Ukraine. The other manifestations of FLW will be discussed in section 2.2, and the relevant literature is summarised in Table 3.

COVID-19

Since the COVID-19 outbreak at the end of 2019, it has shocked all industries and human's normal life, and so does food security. According to the data from 2020, on the same planet, 811 million people are suffering from hunger, 3.1 billion people do not have access to a healthy diet, and 132 million people are threatened by food and nutrition insecurity because of the COVID-19 pandemic (FAO, 2021; "International Day Food Loss and Waste| Technical Platform on the Measurement and Reduction of Food Loss and Waste | Food and Agriculture Organization of the United Nations," 2022). COVID-19 interrupted the food supply chain, ultimately resulting in food waste. It seems the COVID-19 pandemic influence drastically affected food waste for producers (especially the perish products, such as meat, milk, fruit, and vegetables) who are really tied to the food foodservice sector than other food supply chain players, such as processors, foodservice operators, retailers and households (B and M. Kalaitzandonakes, 2020; FAO, n.d.). Even at the beginning, pandemic buying brought food waste to the household stage (Berjan et al., 2022. We can expect the overall pleasant result that food waste could be reduced during the COVID-19 pandemic due to the change in purchase habits, cooking habits, food consumption behavior, attitude to inventory, and leftovers (Iranmanesh et al., 2022). A survey with 3028 samples conducted in New Zealand showed that household food waste was lower during the COVID-19 lockdown than before (Sharp et al., 2021). FAO has concluded the information platform about food loss and waste during the COVID-19 and reduction initiatives (FAO, n.d.).

RUSSIA AND UKRAINE WAR

What is worse, the ongoing war that started in February 2022 between two important world food suppliers, Russia and Ukraine, endangers world food security ("From bad to worse," n.d.; "How will Russia's invasion of Ukraine affect global food security? | IFPRI : International Food Policy Research Institute," 2022; Nasir et al., 2022). These two countries are the top producers of world foodstuffs and fertilizers, and Russia is also the main supplier of oil and gas (Arif Husain et al., 2022). The so-called "World's bread basket" around the Black Sea has been in trouble since the war outbreak ("How will Russia's invasion of Ukraine affect global food security? | IFPRI : International Food Policy Research Institute," 2022; Vlamis, 2022). The war in Ukraine significantly disrupts the normal cultivation, harvest, and transportation in domestic Ukraine and the export logistics (Nasir et al., 2022), which directly causes huge food loss.

However, these two rigorous and unpredictable problems (the COVID-19 pandemic and the Russia-Ukrain war) are not the start of the world food security alarm, a catalyst instead ("Conflict and food security - Security Council, 9036th Meeting | UN Web TV," 2022). We urgently need to take joint action to address food loss and waste for ourselves and the continuation of society.

Table 3. Summary of literature about the other manifestation of FLW

Other manifestation of FLW along FSC in different countries	Reference
COVID-19	Laskowski et al., 2019; S.A, n.d.; "General Provisions ǀ Game ǀ Food Legislation ǀ Legislation ǀ The Food Safety Authority of Ireland," n.d.
Russia and Ukraine war	"How will Russia's invasion of Ukraine affect global food security? ǀ IFPRI : Interna-tional Food Policy Research Institute," 2022; Vlamis, 2022; FAO, n.d.; Sheahan and Barrett, 2017

Source: own construction

DISCUSSION

As Redlingshöfer et al. (Redlingshöfer et al., 2017) suggest that a systematic stepwise investigation is required on food loss and waste topic or serious problem, our research provided a systematic view of the major questions based on food loss and waste across the entire food value chain as food loss and waste vary widely from food sectors to stages of the food value chain.

1. IMPLICATIONS

Food loss and waste have become one of the biggest challenges of the food system, which threaten the sustainability of social, environmental, and economic dimensions (Goldmann et al., 2021). The food loss and waste problem is not only about food security, food safety, and food sustainability but also an ethical problem (Łaba et al., 2022), manifesting in the generation of greenhouse gases, waste of energy, waste of water (Łaba et al., 2022), and lands (Ghosh et al., 2015). However, food loss and waste are not distributed equally in the supply chain steps (Fernandez-Zamudio et al., 2020) and in different countries. We should focus on specific food categories to compare food loss and waste across the food value chain because the magnitude could differ. For example, the processing stage generates minimum food loss and waste in bakery and confectionery (10%) (Goldmann et al., 2021), but in contrast, for some fruits, such as mango (30-80%) (Owino and Ambuko, 2021). The causes of food loss and waste based on Ishikawa diagram is summarized in Figure 1, along with the value chain.

Agriculture is strongly dependent on and vulnerable to natural and weather conditions (Zamudio et al., 2020). Therefore, the main environmental impact of food loss and waste is at the primary production stage (Scherhaufer et al., 2018) and a large amount of total food loss and waste. The primary reasons for food loss and waste are storage conditions controlling (moisture, temperature, pest damage, microorganisms) and unsuccessful transportation (inadequate raw materials quality and transport conditions) (Łaba et al., 2022). The mitigation of food loss at the primary production stage is to reuse lost food to be composted, used for animal feeding, used as raw materials for biofuel, used for biogas plants, or buried in landfill (Łaba et al., 2022). Using proper packaging materials and intelligent storage methods can avoid disease and pesticides (Chen et al., 2022; Maier and Chikez, 2021).

Food loss and waste at the consumption stage include retail, household, and food service providers. The magnitude of the retail part is closely related to retailers' knowledge ("Food Processing and Preservation," n.d.; Mena et al., 2011), such

as the operation of transport (Kamda et al., 2021), packaging, storage (Mena et al., 2011), promotion, and communication between retailers and previous participant industrial processes. Date labelling is a notable criminal for consumers' misunderstanding of purchases, which results in food waste ("'Use by' or 'best before'? |Food Loss Reduction CoP| Food and Agriculture Organization of the United Nations," n.d.). The waste in the household is also a big shock (FAO, 2021; Nations, n.d.; "Tackling food loss and waste," 2022). Innovative marketing tools, such as blind boxes (Yang et al., 2022) and surplus food platforms (munch.hu) ("Munch Mi (T)eszünk a pazarlás ellen! 50-70% kedvezmény!," n.d.; "Munch.hu a platform against food waste | Smart City," n.d.) can improve consumers' intention on surplus food purchases.

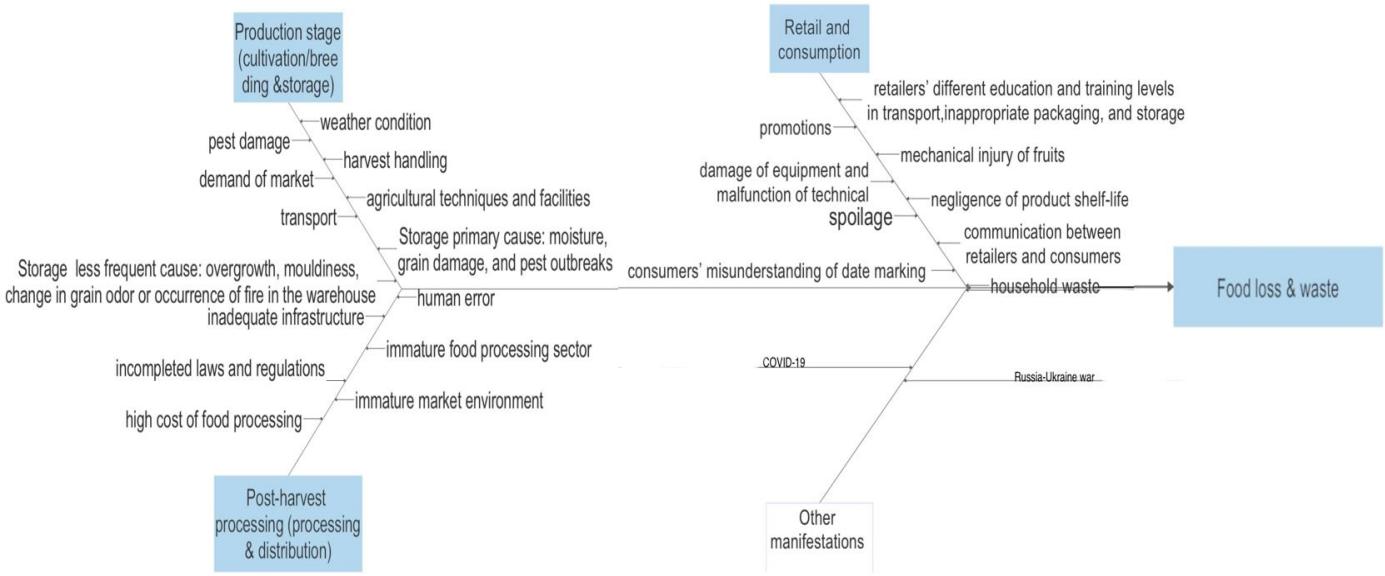

Figure 1. Causes of food loss and waste

Other global events also threaten food security by bringing food loss and waste. For example, a huge amount of food was lost and wasted due to logistics issues (B and M. Kalaitzandonakes, 2020; FAO, n.d.) and pandemic purchases (Berjan et al., 2022) during the COVID-19 pandemic. The Russia-Ukraine war disrupts the normal routine and operation of agriculture in Ukraine (Nasir et al., 2022), normal world foodstuffs, fertilizer, oil, and gas supply from Russia (Arif Husain et al., 2022), and the logistics of agri-food products ("How will Russia's invasion of Ukraine affect global food security? | IFPRI : International Food Policy Research Institute," 2022; Vlamis, 2022).

We suggest all the public and private sectors, stakeholders (farmers, processors and manufacturers, retailers, consumers, food service staff, and so on) in the food value chain and, national and regional governments, politicoeconomic bodies ("The top 10 global political organizations," 2022) (European Union, Association of Southeast Asian Nations, African Union), international organizations (United Nations and its associate agencies, such as FAO ("The top 10 popular associate agencies of the UN and 18 specific agencies, Organization of American States, Shanghai Cooperation Organization, Arab League), international forums (Gulf Cooperation Council, Nordic Council, Council of Europe, North Atlantic Treaty Organization) to take joint actions on mitigating food loss and waste, build a resilient food system and sustainable future for the current generation and future generations.

Official authorities need to strengthen policies, initiatives, and regulations on limiting food loss and waste ("From farm to fork," n.d.; "Resource Efficiency Environment European Commission," n.d.; Redlingshöfer et al., 2017). Public education or training for stakeholders (Goldmann et al., 2021; Kamda et al., 2021) about the consequences of food loss and waste and proper operational skills and technologies (Maier and Chikez, 2021) across the food value chain can help to reduce the food loss and waste possibility from the source. Nutritional education and healthy lifestyle education for individual consumers from childhood and primary school can raise consumers' awareness of reducing food waste ("Diffusion of Innovation Theory," n.d.; Rogers, 1993; Szakos et al., 2021). We also highlight the function of digital education ("Annual Food Waste In Hungary Amounts To 68 Kg Per Person," 2020) in the Industry 4.0 era, which can spread food loss and waste knowledge without time and distance limitations. Global social events also help raise consumers' awareness of food loss and waste, such as building the International Day of Awareness of Food Loss and Waste ("International Day of Awareness of Food Loss and Waste," n.d.).

We argue that ethical level (Lehtokunnas et al., 2022; Roe et al., 2020) and personal lifestyle (people are lack nutritional

knowledge or used to purchasing and overstock food) (Aschemann et al., 2021; Savelli et al., 2019) are the important cause of food waste and food waste at the consumption stage, but which is a lack of enough research, how to improve consumers' awareness and ethical level and change current lifestyle where food loss and waste from reducing food loss and waste is still a promising research agenda.

2. *LIMITATIONS AND SUGGESTIONS FOR FUTURE RESEARCH*

The best way to avoid security issues is to be aware of the risks. After realizing the cause, magnitude, or manifestation of food loss and waste, the measures should be evaluated. Due to the length limitation, we could not provide the knowledge of food loss and waste management measures and proper evaluation.

We suggest that future research on food loss and waste should focus on both edible and inedible parts of commodities (Goldmann et al., 2021). All the food value chain stages should reduce food loss and waste. And there are various measurements tackling food loss and waste. However, we cannot evaluate food loss and waste management from a single viewpoint. What are the avoidable and unavoidable food loss and waste? What is the most efficient solution, and what is the cost of reducing food loss and waste at a particular stage across the food value chain? Is there any added cost for reducing food loss and waste, and how much is it? Are all food loss and waste-reducing measurements beneficial only, not harmful to the environment or economy? Can we have a universal practical solution for food loss and waste reduction, or can the specific solution be practically universal and economically reasonable? We suggest that future researchers pay attention to the effect of food loss and waste-reducing measurements or technologies to select the optimal solution on the topic, which is a need for more investigation in current research on the related topic.

CONCLUSIONS

Due to the whole and broad view of food loss and waste beyond the borders and food value chain stages is still under research, our research contributed to the valuable literature on food loss and waste results from an extensive and comprehensive discussion of the food loss and waste situation in different countries at different agri-food value chain stages based on different food sectors. The major contribution of our research is to clarify that reducing food loss and waste across the food value chain is promising in pursuing food security sustainability. However, the manifestation of food loss and waste is distributed differently in different food value chain stages and on different food types. The main stages where food loss and waste happen are the production stage (cultivation/breeding and storage), post-harvest processing stage (processing and distribution), retail and consumption stage, and other manifestations (COVID-19 and Russia-Ukraine war). Generally, for most food types, the most food loss happens at the production stage. At the same time, most food waste happens at the consumption stage.

We believe the de-growth theory will be helpful in this research field as more people accept the concept and follow it, less food waste through the whole food chain (Latouche, 2007; Takács-György and Takács, 2022; Takács-György and Takács, 2020).

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