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Review paper

Meat matters: tackling food loss and waste in the meat sector

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ABSTRACT

Food wastage occurs throughout the entire food chain, starting from agricultural production and continuing through post-harvest handling, storage, production, distribution, consumption and disposal. Food wastage not only affects food security but also has detrimental consequences for the global economy and the environment. Food loss and waste occur throughout the meat supply chain. According to literature data, 23% of meat production is lost and wasted across all stages of the food chain, with the highest share attributed to the consumption phase. Improved farming practices, animal health management, efficient transport systems, proper storage and handling at processing and retail levels, and consumer education on responsible consumption can all contribute to reducing food loss and waste in the meat sector.

1. Introduction

Globalisation in the 21st century has the potential to bring numerous advantages, especially for developing countries. However, due to the concentration of powerful companies in developed countries and the unequal distribution of profits, the rich have greater access to the benefits of global economic integration, while the poor are left behind, despite experiencing some economic growth. The widening gap between the rich and the poor is a clear indication of the prevalence of hunger and food waste in the world (*Goldsmith*, 2014; *Kilibarda*, 2020). According to a report released by the United Nations Environment Programme (UNEP), it is estimated that approximately 931 million tons of edible food are wasted every year on a global scale (*UNEP*, 2021), and there are currently 820 million people suffering from hunger globally (*FAO*, 2013a; *Kilibarda*, 2020). This issue presents a dual challenge. On one hand, there is a significant problem of overproduction and subsequent waste of food worldwide. On the other hand, the problem of hunger continues to persist and even grow in certain regions like Africa, Latin America and Western Asia (*Karwowska et al.*, 2021; *UNEP*, 2021).

Food wastage occurs throughout the entire food chain, starting from agricultural production and continuing through post-harvest handling, storage, production, distribution, consumption and disposal (*FAO*, 2013b). Although food loss and waste happen worldwide, there is a significant disparity between developing countries and those considered developed. Developing countries primarily experience food loss during the early stages of the food chain, mainly due to limited infrastructure and technological capabili-

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ties (*Kilibarda*, 2020; *Parfitt et al.*, 2010; *Wang et al.,* 2017). In contrast, more developed countries particularly contribute to food waste during the consumption phase (*FAO*, 2013a). Food wastage not only affects food security, but also has detrimental consequences for the global economy and the environment. It leads to increased emission of harmful gases, water wastage, loss of arable land and destruction of biodiversity (*Betz et al.*, 2015; *FAO,* 2013a; *FAO*, 2014; *Wang et al*. 2017). As food is wasted further along the food chain, additional resources and inputs are expended (*Kilibarda*, 2020; *Wang et al*. 2017). The ecological significance of food losses depends on various factors such as the type of food, the stage in the food chain where it occurs, and how it is managed after being wasted or lost (*Bilska et al.*, 2020a). Certain food products, like beef and dairy, are associated with higher consumption of natural resources and have a potentially greater negative environmental impact (*Moult et al.*, 2018). The relationship between food waste and climate change, particularly in terms of greenhouse gas (GHG) emissions, has been a topic of concern (*Bilska et al.*, 2020a). However, studies conducted by *Bryngelsson et al.* (2016) suggest that reducing food waste alone may only result in a modest 1%–3% reduction in emissions, which does not significantly contribute to achieving climate goals. However, taking action to tackle food waste is essential for creating a sustainable tomorrow (*Karwowska et al.*, 2021). Furthermore, promoting shifts towards more sustainable dietary patterns that include reduced meat consumption and increased consumption of plant-based alternatives can contribute to lowering GHG emissions associated with the livestock sector (*FAO*, 2017). By implementing strategies to reduce food waste, improve production efficiency, and adopt sustainable practices, the meat sector can play a vital role in mitigating its environmental impact and working towards a more sustainable and environmentally conscious food system (*Ganeson*, 2023; *Karwowska et al.*, 2021).

2. From farm to fork: addressing food loss and waste in the meat supply chain

Meat products play a significant role in the modern human diet, with an increasing global demand that has led to a steady rise in meat production worldwide. Global meat production has reached approximately 252.6 million metric tons (MT). This production includes 99.1 million MT of chicken, 95.8 million MT of pork and 57.7 million MT of beef (*Wang et al*., 2022). Per capita meat consumption has also shown an upward trend globally, and in 2014, the average person consumed approximately 43 kg of meat annually (*Ritchie & Roser*, 2017). The rise in meat consumption is anticipated to escalate in developing regions, primarily driven by high population levels and growth rates. It is projected that the volume of meat consumption in developing countries will increase approximately fivefold compared to developed countries (*OECD/FAO*, 2020). However, the production of meat and meat products has a significant environmental impact, necessitating the responsible management of the entire production chain, including production, processing, transport and consumption stages (*FAO*, 2017). According to *Gerber et al.* (2013), food animal production contributes to approximately 14.5% of the total human-induced GHG emissions annually, equivalent to 7.1 gigatons of CO_2. Beef production accounts for the largest share of GHG emissions at 35.3%, followed by dairy cattle at 30.1%, swine at 9.5%, and poultry at 8.7%. Methane emissions from ruminants and methane and N_2O emissions from manure storage contribute to approximately 39.1% and 9.5%, respectively, of the total GHG emissions attributed to food animal production.

Meat loss and waste occur throughout the meat supply chain. According to *Lipinski* (2020), 23% of meat production is lost and wasted across all stages of the food chain, with the highest share attributed to consumption (64%), followed by manufacturing (20%), distribution (12%) and primary production and post-harvest (3.5%) (*Caldiera et al.*, 2019). This pattern aligns with the well-known trend in developed regions like Europe, where most waste occurs towards the end of the food chain, particularly at the retail and consumer levels (*Kilibarda*, 2020). While meat accounts for only about 4% of global food loss and waste, data presented by *Flanagan et al.* (2019) and *Ranganathan et al.* (2016) highlight its higher economic value and environmental impact compared to other food groups (cereals, fruits and vegetables). *Buzby & Hyman* (2012) estimated the total value of meat product waste in the United States at approximately 83 million $US. According to *Bux & Amicarelli* (2022), approximately 0.45–0.50 million tons of fresh meat are estimated to be wasted throughout the entire Italian agri-food chain. This waste equates to a value of over €242–268 million. Additionally, there are additional losses in terms of energy and water, amounting to €435–481 million. These findings underscore the importance of

addressing food waste in the meat sector, both from an economic and environmental perspective (*Karwowska et al*., 2021; *Mosna et al.*, 2021).

The reasons for food waste in the meat sector vary depending on the stage of the food supply chain (*Karwowska et al.*, 2021). In their research, *Magalhães et al.* (2020) highlights the "*lack of transportation infrastructures*", "*inadequate handling*", "*poor operational performance*", "*variety of products available in supermarkets*" and "*unhealthy animals and outbreaks of disease*" as the most influential causes of food loss and waste in the Brazilian beef supply chain. Losses at the stage of primary production, as a part of meat sector, can be attributed to farming/rearing conditions and transport to the slaughterhouse. Factors such as poor farming practices, inadequate animal welfare conditions and unfavourable transport conditions can lead to mortality and losses, while some animals are rejected during slaughter due to health or quality concerns (*Gustavsson,* 2011). Disease outbreaks among livestock can result in the loss of animals. To ensure food safety and prevent the spread of diseases, sick animals can be removed from the supply chain, leading to food loss and waste (*Jaja et. al.*, 2018; *Lipinski*, 2020). In the meat processing and manufacturing stage, losses can occur due to trimming, packaging defects and quality control issues. *Dora et al.* (2019) identified several fundamental causes of food losses during the processing stage, including incorrect transportation, product alterations, human error and product defects. Meat and meat products have a short shelf life and require cold storage. If the temperature is not controlled, they can spoil quickly. Additionally, if meat products are not sold before their expiry date, they are wasted, especially at the retail stage. Meat is highly conducive to the growth of microorganisms. The most common risk in relation to meat is the presence of pathogenic microorganisms. When hazards are detected in meat and meat products, that results in losses for food producers and in food waste. During transportation and distribution, factors such as inadequate refrigeration, improper handling and delays can lead to spoilage and loss of meat products (*Lipinski*, 2020). Improper packaging, packaging design, material, and atmosphere influence the product's susceptibility to mechanical damage and microbial contamination, thereby affecting its quality (*Bogataj et al*., 2020; *Zhang et al.*, 2015). The consumption stage plays a significant role in food losses and waste within the food supply chain. According to the literature, the consumption stage, which includes households and food services, is responsible for the largest share of food waste generation in Europe (*Caldeira at al.*, 2019; *Kilibarda et al.*, 2020). Consumers can discard meat products due to improper storage conditions, inadequate knowledge about food preparation, over-purchasing, or personal preferences, packaging size (purchasing larger packages, leading to leftovers that may go uneaten and eventually be wasted) and confusion related to date labels (misunderstandings regarding date labels, such as "use-by" and "best before" dates) (*Bilska et al*., 2020b; *Lipinski*, 2020; *Neff et al*., 2019). Retailers can also generate waste due to overstocking, sensory imperfections or product expiration (*Lipinski*, 2020). Specifically, when it comes to meat, food waste generated in households and food services accounts for 64% of the total food waste in the meat supply chain (*Caldeira at al*., 2019). However, households tend to generate a much larger amount of food waste compared to food service establishments for various food groups, including cereals, potatoes, eggs, dairy and meat.

3. Strategies and innovative approaches to minimise and valorise food loss and waste in the meat sector

In addition to meat, a slaughterhouse produces various other organs and tissues, such as fatty tissues, horns, hoofs, feet, skull, entrails and internal organs, which are mechanically separated from the meat (*Ockerman et al*., 2017). Approximately 45–60% of an animal's total weight is considered suitable for human consumption, while the remaining portion is considered waste (*Chowdhury et al*., 2022). The waste obtained from this sector is known for its complex nature, mainly due to factors such as its pathogenic nature, high water content, propensity for rapid auto-oxidation, and elevated levels of enzymatic activity (*Jayathilakan et al.*, 2012). The waste generated from a slaughterhouse can be broadly categorised into solid waste and liquid waste. For the treatment of solid waste and possibly its valorisation, *Sabumon* (2023) suggests following strategies within waste management: anaerobic digestion, composting, rendering, alkaline hydrolysis and enzyme application. For wastewater management from slaughterhouses, *Sabumon* (2023) states as possible solutions, land application, physicochemical treatment, biological treatment, advanced oxidation processes and combined processes, while for blood waste management, the author suggests proper col-

lection and separation and then its utilisation and treatment. Bones, as waste from meat sector, contain valuable elements such as phosphorus and calcium that can be used as the basis for other products. By utilising thermal methods, it is possible to obtain significant amount of hydroxyapatite ash from this waste, which can serve as a substitute for phosphorites and has the potential to be used to produce food-grade phosphoric acid and mono- and dicalcium feed phosphates (*Kowalski et al*., 2021). The recycling of residual animal fat from industrial meat processing for biodiesel production offers an attractive renewable energy source (*Skoronski et al*., 2016). Using food waste as animal feed presents a solution that addresses waste management and food security challenges. By incorporating these food wastes into animal diets, we can maximise their value, minimise waste and contribute to a more sustainable and efficient food system (*Rajeh et al*., 2020). This is evident in various aspects, including a reduction in GHG emissions by 56.40%, a decrease in water consumption by 22.62%, a significant reduction in land use by 87.50%, and a decrease in fossil resource scarcity by 21.78% (*Mosna et al*. 2021). According to *Araújo dos Santos et al*. (2023), handling poultry litter for biogas production and reusing poultry waste to produce meat meals in feed production resulted in the avoidance of methane and ammonia emissions, leading to a reduction of over 55% in environmental indicators such as climate change, terrestrial acidification, and freshwater eutrophication.

Smart packaging materials (active and intelligent packaging) are a rapidly emerging technology that offers various features for monitoring the condition of packaged products. These systems enhance the interaction between consumers and food products, offering a unique consumer experience while providing clear data, traceability and trackability, and decreased risk of food wastage (*Ganeson et al.*, 2023).

Consumer education, awareness campaigns and strategies for better meal management and food storage can help reduce food waste in households. Efforts to reduce food waste at the consumer stage should focus on promoting proper storage practices, providing consumer education on food preparation and portion control, and improving understanding of date labelling. By empowering consumers with knowledge and tools to minimise waste, significant progress can be made in reducing food loss and waste in the meat sector (*Martin-Rios et al*., 2018; *Reynolds et al*., 2019). Furthermore, while food service establishments generate a smaller proportion of food waste than do households, they still have a role to play in waste reduction. Improving portion control, menu planning, inventory management and donation programs for excess food can help minimise waste in the food service sector (*Kilibarda*, 2020; *Kilibarda et al*., 2020).

4. Conclusion

Addressing the unequal distribution of the benefits of globalisation, as well as combating hunger and reducing food waste, is crucial. Efforts should be made to promote fair economic exchange and ensure that the advantages of globalisation are accessible to all. Furthermore, initiatives should focus on improving infrastructure and technology in developing countries to reduce food loss, while in developed countries, consumer behaviour and attitudes towards food should be addressed to minimise food waste and its negative impact on the environment. Addressing causes of food loss and waste in the meat sector requires interventions at each stage of the supply chain. Improved farming practices, animal health management, efficient transport systems, proper storage and handling at processing and retail levels, and consumer education on responsible consumption can all contribute to reducing food loss and waste in the meat sector. By addressing these causes, the meat sector can contribute to minimising food waste and maximising the utilisation of valuable resources.

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