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STRATEGIES FOR PREVENTING AND REDUCING FOOD LOSS AND WASTE ACROSS THE AGRI-FOOD CHAIN: EVIDENCE FROM A MULTI-ANNUAL RESEARCH INITIATIVE

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Abstract

Ensuring food security and addressing poverty and hunger constitute critical challenges for humanity. The security and sustainability of our food can be achieved by eliminating the causes that lead to food loss and through measures that can be taken by all stakeholders in this phenomenon. The aim of the paper is to identify concrete measures to mitigate food loss in the agri-food chain. The study forms part of a multi-annual research initiative and employs both quantitative and qualitative methodologies to address the three objectives established. In addition to a comprehensive review of the relevant literature and the analysis of data from official sources, empirical evidence was gathered during a workshop conducted in person in June 2025. The resulting data were systematically synthesized, processed, and interpreted, and presented in tabular and graphical form. The findings highlight practical solutions for reducing food loss (FL) and food waste (FW) at the farm level, within processing and distribution, in the food service sector, and among households. Emphasis is placed on the role of public policies and social responsibility programs in supporting these efforts.

Key words**:** *food loss, food waste, reduction, consumers, supply chain*

INTRODUCTION

In 2024, approximately 32% of the global population could not afford a healthy diet, while 8.2% experienced hunger. In this context, food sustainability [16] and food security are universal concerns, encompassing equitable access to food, its availability, and its responsible utilization [17]. The food system plays a crucial role in achieving Sustainable Development Goals (SDGs) 2 and 12, adopted by the United Nations in 2015, various authors reporting the need to implement solutions to reduce food loss. [13, 35].

In Romania, the share of the total population facing moderate or severe food insecurity during the period 2022–2024 was 18.6% (Figure 1), one of the highest rates in Eastern Europe (compared to Albania 33%, Ukraine 32.5%, Republic of Moldova 25.1%, Hungary 15.6%, North Macedonia 15.2%, Bulgaria 11.6%, and the Czech Republic 10%) [18].

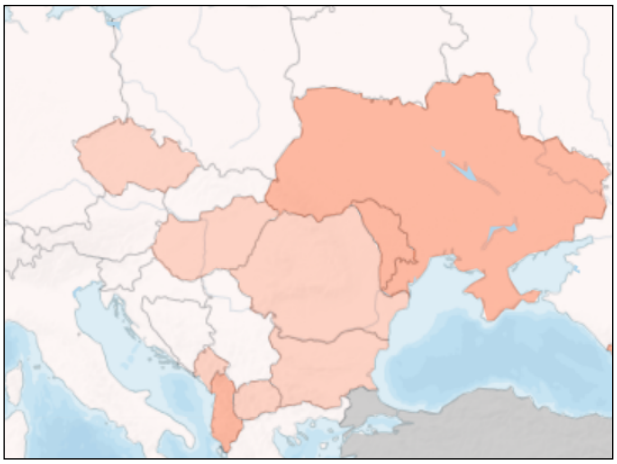

Fig. 1. Map of Moderate or Severe Food Insecurity in Eastern European Countries
Source: caption from [18] .

Against this backdrop, food waste represents a major and complex challenge [38]; its reduction can mitigate hunger, pollution, and biodiversity loss [3, 39], thereby serving as an integral component of ensuring food security and a shared responsibility among all stakeholders.

According to the United Nations Environment Program (UNEP), in 2022 food waste levels were particularly high in several European countries, reaching 168 kg/person in Portugal, 157 kg/person in Cyprus, 144 kg/person in Malta, and 132 kg/person in Italy, all of which exceeded the global average of 132 kg/person [37].

Various studies have shown that the amount of food waste generated at the household level depends on socio-demographic factors as well as on purchasing and food management practices [10, 24], which underscores the need for intervention measures tailored to different categories of consumers. Chereji (2023) [6] reported that younger populations generated larger quantities of food waste, regardless of their place of origin.

Food loss and food waste arise from multiple causes along the supply chain (Figure 2):

-Consumer-level causes: inadequate shopping and meal planning, impulse buying, poor inventory management, over-preparation of food, inappropriate handling of leftovers, and confusion over date labeling.

Fig. 2. The word cloud regarding the FL and FW
Source: created with [34].

-Supply chain causes (production, processing, distribution, retail): insufficient investment in efficient technologies, poor management, losses during preservation, overproduction and overcooking (HoReCa sector), spoilage, food preparation leftovers, and unfair commercial practices.

Good Practices for Preventing and Reducing Food Loss and Waste (Figure 3)

-Consumer-level practices: careful shopping and meal planning, avoidance of impulse purchases, effective inventory management, preparing appropriate portion sizes, creative use of leftovers, and accurate interpretation of date labels (e.g., "best before" vs. "use by") [5].

-Supply chain practices: investment in innovative technologies, efficient resource management, facilitation of food donations, price reductions for products nearing the end of their shelf life, improved packaging and transportation, adoption of digital and technological solutions, and the transition toward a circular economy [19, 20, 35]. These measures emphasize the continuous and efficient use of resources and the minimization of waste [1].

Fig. 3. The word cloud regarding the actions aimed at combating FW
Source: created with [34].

Addressing Food Waste Requires Coordinated Efforts from All Stakeholders

-Role of consumers: Everyone plays a crucial role by adopting responsible consumption habits.

-**Role of entrepreneurs and the food industry**: Through strategic investments, efficient management, price reductions, and food donations.
-**Role of policymakers**: By developing updated regulations, clarifying legislation, and providing financial support.
-**Collective responsibility**: Through the joint effort of all individuals to reduce FW, the food system can undergo transformative changes towards a circular economy.
The aim of this paper is to identify strategies to prevent and reduce FL and FW at various stages of the agri-food chain.

MATERIALS AND METHODS

Study Design

This study was conducted as part of a multi-year research project aimed at identifying concrete actions to reduce FL and FW in Romania.
A mixed-methods approach was employed, integrating a systematic content analysis of relevant literature with survey-based data collection during a workshop conducted in June 2025.
During the event, statistical data from different countries regarding FL and FW were presented, examined key legislative frameworks, and outlined the obligations of economic operators to minimize and valorize food waste in alignment with circular economy principles.
The second phase of the workshop involved structured open discussions, during which representatives from the food industry and agricultural sector presented concrete interventions implemented to mitigate food loss and waste and discussed the principal operational challenges encountered.
Data were collected through paper-based questionnaires, comprising primarily five-point Likert scale items, supplemented by open-ended questions to capture qualitative insights.
All participants were informed of the study's objectives and data protection procedures in accordance with GDPR requirements.
Collected data were systematically processed and analyzed using Microsoft Excel v.365 (Microsoft Corporation, Redmond, WA, United States).
Table 1 presents the primary objectives of the study.

Table 1. Objectives of the studies

Main objectives in the second study
O.1 Identification of measures to reduce FL to the farmers
O.2 Identification of actions to reduce FL at processors and wholesalers
O.3 Identification of actions to reduce FW at the end of the agri-food chain (in the HoReCa system and at the household consumption level) and social responsibility

Source: own design.

Study Participants

A total of 14 respondents completed the paper-based questionnaire administered during the workshop on 4 June 2025. The participants had a mean age of 29.5 years (range: 19–50), with equal representation of males and females. Most participants (57.1%) resided in urban areas. Half of the respondents were high school graduates, currently students from family farms or employed by food processors, while the other half held higher education degrees. By region, 85.7% were from Sibiu County, with the remainder from neighboring counties Alba and Vâlcea.

RESULTS AND DISCUSSIONS

O1 Identification of measures to reduce FL to the farmers

Workshop participants highlighted several strategies to mitigate food loss at the farm level (Table 2). The most important measure, according to the respondents, is the implementation of disease and pest monitoring systems in both the field and storage facilities, which received a mean score of 4.57. Equally important is the use of data collection, storage, and analysis systems, enabling timely and informed decision-making (mean score: 4.50).
The use of sensor systems connected to the Internet of Things (IoT) received the lowest rating (mean score: 3.79), reflecting the additional requirements for specific digital skills and adequate infrastructure.
These findings underscore the relative feasibility and perceived effectiveness of

different technological interventions for reducing farm-level food loss.

Table 2. Assessment of the Importance of Food Loss Reduction Measures at the Farm Level

Measure	Mean score	Rank
Use of disease and pest monitoring systems	4.57	1
Use of field data collection, storage, and analysis systems (Big Data) to generate actionable crop insights	4.5	2
Use of irrigation monitoring systems and smart irrigation technologies	4.14	3
Use of drones for crop monitoring	4.07	4
Use of IoT-connected sensor systems	3.79	5

Source: own calculation.

Use of Storage and Preservation Systems to Reduce On-Farm Crop Losses

Responses from the workshop indicate that among strategies to reduce on-farm crop losses, the most highly rated measure is the implementation of monitoring and control systems within storage facilities, which received a mean score of 4.36 (Figure 4).

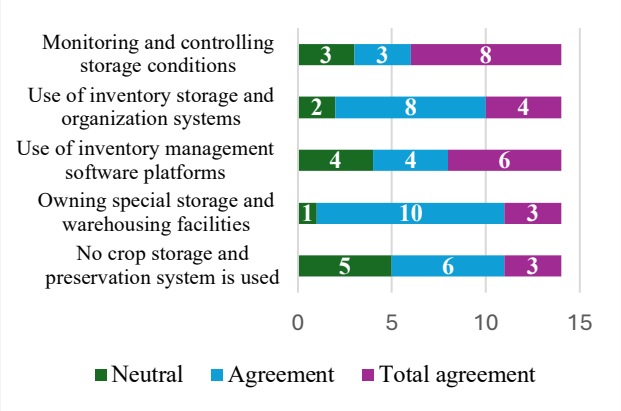

Fig. 4. The importance of using crop storage and preservation systems
Source: own design.

Such systems enable real-time tracking of storage conditions, early detection of spoilage, and prompt corrective actions, thereby minimizing post-harvest losses. These findings highlight the critical role of storage management in maintaining crop quality and reducing overall food loss at the farm level, complementing field-level interventions such as pest and disease monitoring.

Importance of Infrastructure Investments as Measures to Reduce FL at the Farm Level

In Romania, the platform "Solution4Farming" has been developed for mixed farms and tailored to the country's pedoclimatic conditions, serving as a direct link between digital agriculture solutions and sustainable production practices. The platform enables the measurement of greenhouse gas emissions, on-farm losses, and water consumption relative to the farm's livestock [31].

The primary infrastructure investments required to reduce agricultural production losses at the farm level (Figure 5) include the acquisition of automated harvesting and handling systems—such as GPS-equipped tractors, combines, and other machinery to enhance operational efficiency—which received a mean score of 4.43. The use of Blockchain technology for tracking the agricultural supply chain from farm to consumer was also highly rated, with a mean score of 4.21. All categories of infrastructure investments received mean scores above 4.0, indicating their perceived importance.

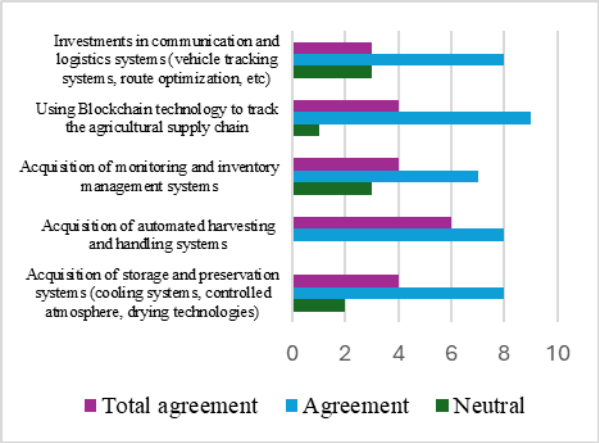

Fig. 5. The importance of investments in farm infrastructure as measures to reduce on-farm food loss
Source: own design.

Integrating Blockchain technology facilitates the application of sustainable agricultural practices and ensures the stability of the food supply chain [33]. Innovative smart agriculture

solutions further contribute to increased productivity, optimized resource use, and the traceability necessary to guarantee food safety [2].

Forms of Support to Assist Crop Management at the Farm Level, According to Workshop Participants

In response to an open-ended question regarding the types of support needed by farmers, workshop participants suggested the following measures, summarized in Figure 6:

-User-friendly smart devices;
-Comprehensive crop monitoring with alerts for potential issues;
-Establishment of associations or cooperatives to secure clients for products and provide adequate storage facilities;
-Promotional campaigns for small-scale producers;
-On-farm processing of raw materials;
-Investments in modern technologies, including advanced machinery, GPS systems, and drones;
-Provision of financial support and subsidies for farmers;
-Implementation of agricultural insurance;
-Direct contractual agreements with buyers.

Fig. 6 The word cloud of resulted from open question regarding to the forms of support needed for farmers
Source: created with [34].

These suggestions highlight the multifaceted support required to enhance farm management, improve efficiency, and reduce

O2 Identification of actions to reduce FL at processors and wholesalers

Measures to Reduce Food Waste at Processors

The most important and effective measure identified in this sector is the establishment of a legal framework and infrastructure for the formal management of food waste, which received a mean score of 4.5. This is followed by the creation of start-ups aimed at developing solutions to optimize the management of food loss (mean score: 4.43) (Table 3).

Previous studies indicate that food processors often implement their own solutions to recover and reuse by-products, thereby minimizing waste [9, 15].

Table 3. Preferences for Measures to Improve Food Waste Management at Processors

Measure	Mean score	Rank
Legal framework and infrastructure for formal food waste management	4.50	1
Funding for start-ups developing solutions to optimize food waste management	4.43	2
Tax incentives for staying within a defined food waste threshold	4.07	3
Penalties for exceeding the established food waste threshold	3.57	4
Don't know	3.14	5

Source: own calculation.

Measures to Reduce Food Loss at Distributors

Most participants believe that distributors must have intelligent inventory monitoring systems that monitor consumption, product spoilage, and expiration dates.

O3 Identification of actions to reduce FW at the end of the Agri-Food Chain (HoReCa and Household Level) and Social Responsibility

Importance of a Digital Support System for Food Waste Management in HoReCa

More than 90% of workshop participants emphasized the importance of a digital platform to manage food waste in the HoReCa sector. Devaraj and Balasubramanian (2025) [12] report that the service sector generates approximately 28% of total annual food waste, highlighting the need for tailored avoidance strategies. Managerial practices in this sector often prioritize customer satisfaction, with insufficient attention to food waste reduction [26]. Various authors have reported as

identified measures to reduce FW in public catering the redistribution of food, the use of leftovers from plates for animals, and the use of various technical equipment and mobile phone applications. [14, 29].

The importance of collaboration within the food chain

Over 90% of the workshop participants positively assessed the need for collaboration between all stakeholders in reducing FL and FW.

Measures to Reduce FW in the family

Kalogiannidis (2025) [22] shows that FW at the household consumer level exceeds 50% of its total at the food chain level. Any intervention aimed at reducing household waste positively contributes to food security [23]. According to the workshop participants, the most effective measure at the household level is proper inventory management, including checking and prioritizing food consumption depending on the expiration date (average score: 4.43). All the actions they scored over 4 points, all of which were important from the participants' perspective.

Table 4. Measures to Reduce Food Waste at the Household Level

Measure	Mean score	Rank
Checking and prioritizing the use of food according to expiration dates	4.43	1
Reusing leftovers from the refrigerator	4.21	2
Menu planning with the preparation of a shopping list	4.07	3
Purchasing smaller quantities and cooking smaller portions	4.07	4
Buying food at discounted prices near the end of its shelf life	4.00	5

Source: own calculation.

Study participants emphasized the need for national awareness and education campaigns on this topic, which received a mean score of 4.71. The second preference (average score 4.50) referred to the need for investments in re-technologies and innovation. (Table 5)

Several studies [4, 28] indicate that education and awareness remain essential for young consumers to develop responsible and sustainable behaviours that contribute to the reduction of food loss. Universities have a critical role in this process through formal education, supporting the use of mobile applications, smart packaging based on nanotechnology, and promoting ecological awareness [27]. Consumer education on food waste reduction should begin at home and continue throughout the school curriculum [40], informed by research on ecological, moral, financial, and social motivations related to minimizing food waste [32].

Table 5. Additional Measures Contributing to the Reduction of Food Waste

Measure	Mean score	Rank
Awareness and education	4.71	1
Investments in technology and innovation	4.50	2
Recovery, reuse, and recycling of food waste (e.g., for animal feed, biochemical processing, anaerobic co-digestion, composting/aerobic processes, controlled combustion, or integration into the circular economy)	4.36	3
Correct understanding of food labeling (distinguishing “best before” vs. “use by” to reduce consumer-level waste)	4.29	4
Price reductions on products nearing expiration (e.g., sale with discount labels)	4.29	4

Source: own calculation.

Workplace-Applied Solutions Identified by Participants

In response to an open-ended question, participants suggested several practical measures applicable in their work settings, including: efficient management of raw material stocks using the FIFO (“First-In-First-Out”) method; delivery of food products following FIFO principles; production planning and manufacturing of smaller batches; strategic planning of raw material procurement; correct portion sizing; creation of short-term inventories; discounting products nearing expiration; utilization of food waste for animal feed; use of modern training methods on food waste reduction; and effective communication strategies regarding FW.

Importance of Social Responsibility Policies and Programs

Approximately 86% of respondents emphasized the importance of policies and programs enabling the donation of surplus food to vulnerable populations through food banks, charitable organizations, or local communities. Other studies support the need for national policies promoting responsible consumption, public education campaigns [7, 8, 10, 14, 30, 36], and collaboration among all stakeholders to diminish FW [11, 21, 25].

CONCLUSIONS

During the workshop, several concrete actions aimed at avoiding food waste were prioritized:

Farm Level:

-Implementation of crop and storage monitoring systems for diseases and pests;

-Investments in storage facilities equipped with temperature, humidity, and gas sensors;

-Acquisition of modern automated harvesting and handling systems;

-Provision of various forms of support for farmers to reduce raw material losses.

Processors and Distributors:

-Establishment of a legal framework and infrastructure for monitoring and managing FL and FW;

-Application of measures to improve food waste management;

-Implementation of inventory management systems to monitor consumption, spoilage rates, and expiration dates.

HoReCa Sector:

-Support for the creation and acquisition of digital platforms to manage FW;

-Establishment of partnerships between farmers and food service units for the valorization of FW.

Household Level:

-Improved management and verification of food stocks, prioritizing consumption based on expiration dates;

- Organizing non-formal education actions and population awareness campaigns to demonstrate the long-term effects of FW on food sustainability.

Social Responsibility Policies and Programs:

Awareness of stakeholders regarding policies and programs for donating surplus food to vulnerable populations.

The study also identified gaps in knowledge and skills regarding composting of household FW. Major barriers to effective FW reduction include the lack of a globally accepted definition, absence of standardized reference levels, inconsistent interpretations of legislation, issues related to value-added tax on food, and unfair commercial practices.

Reducing FW, community involvement, implementation of high-performance, innovative technologies, and collaboration are essential.

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