DOI: https://doi.org/10.21323/2414-438X-2023-8-1-51-61

Available online at https://www.meatjournal.ru/jour
Review article
Open Access

Received 14.02.2023
Accepted in revised 13.03.2023
Accepted for publication 20.03.2023

ASSESSMENT OF CAUSES AND CONSEQUENCES OF FOOD AND AGRICULTURAL RAW MATERIAL LOSS AND OPPORTUNITIES FOR ITS REDUCTION

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Keywords: *food loss, waste, sustainable development goals, SDG 12.3, national strategies, food supply chain, animal husbandry, processed products, meat industry*

Abstract

The article summarizes and systematizes the causes and consequences of food loss and waste. The uncontrolled accumulation and inefficient management of loss and waste is a serious problem of food security in many countries. Moreover, the world annually loses or wastes about a third of food produced while natural resources are inefficiently used. A significant number of definitions and terms in the field of food loss and waste cause international inconsistency in management systems. So, systematization of terms and research methods for food loss and waste has been carried out. The review analyzes the stages of food supply chain, i.e. the production of agricultural raw materials, their collection, processing, transportation and consumption, where the largest loss and waste occur. Furthermore, environmental, social and other problems associated with the accumulation of loss and waste are considered. Prevention of food loss and waste has been shown to be a potential strategy to improve the balance of food supply and demand and is essential for improving food security while reducing environmental impact and providing economic benefits to various participants in the food supply chain. Separately, the actions taken by the Russian Federation in the field of waste management and reduction of food loss are considered. Attention is drawn to the fact that the difficulties in solving these problems are associated with insufficient progress in legislation and low funding of relevant research projects. Possible approaches for simulation and optimization of actions to support specific strategies to reduce loss and waste are considered, taking into account the following factors: improving the management of various inventories; developing a clear strategy for planning and allocating resources; forming the supply chain based on variability (uncertainty) of customer demand and supply. Knowledge comparison and integration, as well as optimization of food supply chain management are essential for development of strategies and decisions about where and how to focus efforts to most effectively ensure the reduction of loss and waste at each stage of food supply chain. The main decisions and practices for FLW prevention and management have been systematized.

For citation: Petrunina, I.V., Gorbunova, N.A., Zakharov, A.N. (2023). Assessment of causes and consequences of food and agricultural raw material loss and opportunities for its reduction. *Theory and Practice of Meat Processing*, 8(1), 51-61. https://doi.org/10.21323/2414-438X-2023-8-1-51-61

Funding:

The article was published as a part of the research topic No. FNEN-2019–0005 within the state assignment of the V. M. Gorbatov Federal Research Center for Food Systems of RAS.

Introduction

According to the UN Food and Agriculture Organization (FAO), by 2050, the world population will reach almost 10 billion people, which will require an increase in food production by at least 70% [1].

Today, the world produces enough and even excess food to meet the needs of the entire population of the planet. According to an analysis of data from the FAO Statistical Yearbook [2], about a third of food produced for human consumption is lost or wasted worldwide, which is about 1.3 billion tons per year [3]. In terms of calories, global food loss and waste (hereinafter referred to as FLW) account for approximately 24% of all food produced, which is equivalent to 614 kcal/person/day [3].

At the same time, according to the UN Food and Agriculture Organization (FAO), more than 821 million people suffer from hunger in different regions of the planet [4].

The growth in the production of food raw materials and foodstuffs is accompanied by an increase in FLW levels. This issue has now become a major restriction for global sustainability, with adverse impacts on food security, natural resources and human health. Therefore, the reduction of FLW is one of the important goals for the world community [5, 6].

The FLW issue was most comprehensively discussed at a United Nations special event in 2015. As a result, UN member countries adopted 17 Sustainable Development Goals (hereinafter referred to as SDGs) for the period up to 2030. These activities are aimed at the elimination of poverty, hunger and improving life quality of the population. One specific target is to halve food waste and loss by 2030 (SDG 12.3). Already now, the adoption of the SDGs

has made it possible for different states to form a general idea of the existing problems in relation to FLW, determine approaches to their solution and introduce several key concepts in this area [7].

There are two main challenges for achieving SDG 12.3. First, there is no reliable global measurement of FLW. Second, the reduction of FLW is not a goal in itself, but a means to establish responsible consumption and production in world practice. This implies a reduction in the economic, environmental and social costs associated with the nutrition of the population, while improving food security [8].

In this regard, the Voluntary Code of Conduct for Food Loss and Waste Reduction developed by FAO should be mentioned. This set of rules aims to achieve a reduction in FLW based on internationally agreed principles and standards of responsible practice [9].

Today, most countries of the world are working on global strategies to reduce FLW, which take into account food waste at each stage of the food chain, combining economic interests with maintaining the natural balance of the ecological system and sustainable environmental management [10,11,12].

Systematization of terms and methods for FLW research

The scientific community has formed a glossary of unified terms and definitions, which makes it possible to appeal to the conceptual framework in the field of sustainable development goals in relation to the triad of "food security and nutrition", "sustainable food systems" and "food loss and waste". However, there are different approaches to separating the concepts of "food loss" and "food waste". What remains unchanged is that the concept of food loss refers to the initial stages of the agri-food value chain, i.e. the growing of cultivated plant and the primary products obtained from their processing. As for food waste, they appear at subsequent stages of this chain, i.e. in retail and during consumption [2,13,14].

Despite the existing glossary, various participants use many of their own definitions and terms for food systems [15]. Because of this inconsistency, there are international nonconcurrences in loss and waste monitoring systems. According to some experts [16], differences in the definition of FLW arise when taking into account such different factors as:

- actual or estimated FLW levels;
- main types of FLW based on their qualitative or quantitative assessments;
- the use of FLW for human consumption or the lack of such possibility;
- application of "edibility" and "nutritional value" criteria to FLW;
- time spent when using FLW (pre-harvest, ready-to-harvest, post-harvest activities);
- prospects for using FLW to improve environmental, social, and food security.

In this regard, it is reasonable referring to the approaches to these issues from the FAO Global Initiative on Food Loss and Waste Reduction [17] and the FAO Technical Platform on the Measurement and Reduction of Food Loss and Waste [18]. According to these organizations, the characteristic of food loss is a decrease in food quantity or quality as a result of activities by food suppliers, excluding retailers, food service providers and consumers. Food waste is the reduction in food quantity or quality as a result of the decisions and actions by retailers, food service providers and consumers.

The significant differences between food loss and food waste are not only conceptually significant. This is also important for entrepreneurs, whose actions affect the appearance of loss and waste. In addition, this circumstance implies the choice of ways to both reduce FLW levels and further use them. In particular, when estimating the amount of FLW, it should be taken into account that uneaten food may be processed into by-products that also have economic value. If these products are redirected to other uses, such as animal feed, they will not be considered as quantitative loss or waste, despite the possible reduction in their economic value. In addition, when calculating FLW amount, it is not recommended to take into account inedible parts of products [19].

The Food Loss and Waste Accounting and Reporting Standard [20] (hereinafter referred to as the FLW Standard) was developed by the Food Loss and Waste Protocol Partners. The standard consists of ten steps, starting with defining the purpose of the loss assessment and ending with the establishment of a way to monitor the relevant processes. The FLW Standard provides guidance on methods for quantifying FLW, including their direct measurement, as well as analysis of their composition, mass balance calculations, and other actions. This Standard may be applied at an individual enterprise and at the country level in order to determine the location and extent of FLW formation and how they can be used to reduce environmental impact [20].

In addition, indicators are being developed at the international level to simplify the process of monitoring the FLW level. The indicator recommended for use at the national level is the rate of food loss and waste per capita in a given country. It is expressed in kg/person/year and consists, in turn, of two indicators. The first one covers loss from the agricultural farm to the distribution points of the agri-food chain (food loss index). The second one describes the loss that occurs at the stage from trade enterprises to households (food waste index) [21].

At the level of the European Union, the FUSIONS (Food Use for Social Innovation by Optimizing Waste Prevention Strategies) project [22] implemented within the framework of the Seventh Framework Program of the European Commission in 2012–2016 should be noted. This comprehensive research project is dedicated to developing a method to measure and prevent food loss and waste in

the EU countries. The FUSIONS program does not separate edible and non-edible food parts, but covers the entire flow of resources removed from the supply chain.

This project considers redistribution as part of the food supply chain up to the point of consumption. According to FUSIONS, waste refers to food that is still fit for consumption but does not meet established criteria for sale. Such foodstuffs include seasonal products, excess inventory, products that are mislabeled or damaged during transportation. The results of the project show that there is no one universal method that allows obtaining representative data. Therefore, to achieve representativeness, it is recommended to use several research methods simultaneously. A proclamation has been issued to all organizations that collect data on food waste to do so in accordance with the FUSIONS guidelines. This is necessary in order to ensure the comparability of data obtained at all stages of food supply chain in the EU countries [23].

Russian experts believe that the further formation of a conceptual framework in the field of minimizing food loss will make it possible to develop a number of harmonized regulatory documents that will help ensure Russia's food security. Thus, saving of food resources by reducing the FLW arising in the technological cycle is an important way in solving economic, social and environmental problems [24].

Analysis of measures to reduce FLW, taking into account the interests of participants in the value chain

When considering the issue of FLW reduction from the point of view of the entire value chain sustainability, it is important to take into account the interests of its main participants. Some of them may lose and others may benefit from appropriate loss reduction measures. A comprehensive consideration of interests is necessary to determine the possibility of sharing financial and other costs between participants. Therefore, when choosing methods to reduce FLW, it is necessary to identify the economic and behavioral factors that led to the occurrence of loss and waste.

To date, there is insufficient information to understand in detail the socio-economic consequences of food and agricultural raw material loss. Therefore, there has been a long debate about the extent to which the investment in reducing FLW outweighs the cost of developing measures for this purpose. In this regard, the question is relevant: what "loss" is acceptable [3].

On the one hand, in order to achieve significant results in reducing FLW, it is necessary to identify the benefits for each of the participants in this process. For example, a supplier may receive additional economic benefits, and a trade enterprise may increase its reputation in the eyes of consumers. The physical availability of food may improve the diet and well-being of consumers. In addition, the reduction of FLW may improve food and environmental security at the state level [25,26].

On the other hand, it should be taken into account that the reduction of FLW cannot bring benefits to all participants in this process. Among others, most vulnerable elements of the value chain are farmers, other small producers and food processors. For them, both the positive and negative consequences of the FLW reduction are more noticeable [4]. Thus, farmers, other producers and consumers may be interested in reducing FLW in order to increase their welfare. However, the existing incentives for realizing such an interest are often not enough. The benefits of reducing FLW do not always justify the money or time invested in them. For example, individuals may face some institutional barriers: credit restrictions or a lack of information about possible actions. At the same time, the government sector is almost always interested in reducing FLW, since successful results in this area help to increase the food security of vulnerable population groups and reduce environmental damage [19].

According to experts, in the world, on average 30% of all food produced, or 1.3 billion tons per year, is lost or misused [2]. Figure 1 shows the loss of food products at the main stages of production, i.e. from growing to sale [27].

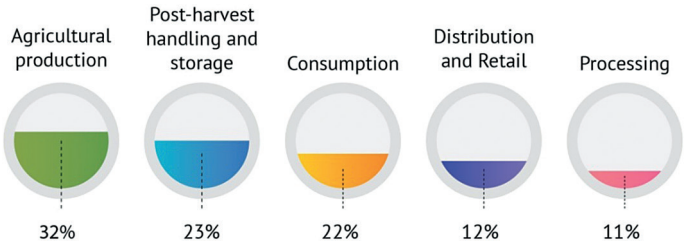

Figure 1. Food loss at the main stages of production (%) [27]

As for the type of food items that are lost all over the world, the statistics depend on whether FLW is measured in calories or in weight. In terms of calories, cereals make up the largest share of the global FLW (53%), followed by roots and tubers (14%), fruits and vegetables (13%). Meat makes up a relatively small share, though not in terms of environmental impact, i.e. 7%. However, on a weight basis, fruits and vegetables are the largest source of FLW (44%), followed by roots and tubers (20%). If we estimate the level of FLW for each commodity production, then 20% to 22% of the total volume of cereals produced is lost, compared to 39% to 44% of fruits and vegetables, 33% of roots and tubers, and 24% of seafood [3].

Figure 2 shows the specific loss for certain types of food products [28].

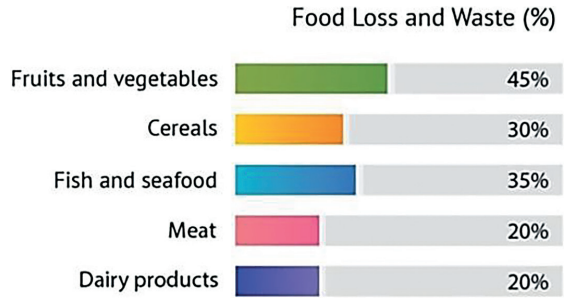

Figure 2. Food loss and waste by food type (%) [28]

Food loss and waste is highly dependent on the specific conditions and local situation in a given country or culture [15].

Environmental issues in the formation of FLW

In a modern world, there is a clear depletion of natural resources, which requires increased environmental control and a more environmental friendly approach, taking into account the labor costs of producing agricultural products and food, organizing supply chains, as well as preparing the land, using fertilizers, and other costs associated with agricultural production [3,29].

Thus, 173 to 250 km^3 of water per year is spent on the production of lost and wasted food products. Food crop production uses approximately 24% of total fresh water resources (27 m^3/person/year) and one fifth of fertilizers (4.3 kg/person/year) [30]. The area of arable land used to grow unused food is 198 million hectares per year, which is one fifth of the arable land used worldwide for food crops, or an area of Mexico size [3]. Reducing FLW will help to decrease the use of land, water and nutrients, as well as external negative impacts on the environment [12].

At the same time, due to the formation of unclaimed products, a significant part of the economic and natural resources spent on its production (labor, water, energy, soil, and others) is wasted, many of which are limited. Global food loss is estimated at a level of $7.5 trillion annually [4].

Efforts to reduce food loss and waste aimed at more rational consumption and production of food may play an important role in ensuring food and environmental security, contribute to solving economic and social problems, and increase the sustainability of value chains both at the regional, federal, and international level.

Most often, the solution to the problem of providing the population with food is seen in one way, i.e. increasing the production volumes by improving the technical means of agriculture and the processing industry. Some business experts think about this situation as about an insoluble contradiction between environmental requirements and real production. Therefore, there is a critical attitude towards the position of the environmental groups. All their proposals are thought to be aimed only at a sharp reduction in the volume of industrial activity. But such an opinion is not sufficiently substantiated. The presence of different approaches to the choice of methods and directions in economic development is quite a normal. However, this circumstance does not prevent the wide use of the achievements of scientific and technological progress for environmental purposes. Thus, increasing production volumes while reducing the level of negative impact are not opposed to each other [31].

For example, let's consider the meat industry in Russia. The production activity of almost all enterprises in this industry has a negative impact on the environment. First of all, this concerns emissions and discharges of pollutants, as well as waste disposal. The volume of this impact varies significantly and depends on the capacity of enterprises, as well as on the technologies and equipment used at the main stages of the production process. Thus, the degree of equipment of the meat industry with modern technical means directly affects not only the quality of products, but also the level of negative environmental impact [32].

In Russia, there are a number of regulations in the field of environmental management. These documents provide, in particular, financial and other forms of liability for violations of a number of requirements and rules. For example, the Code of Administrative Offenses of the Russian Federation[1] introduces penalties for non-compliance with environmental requirements when managing livestock, production and consumption waste. The need for strict regulation of this area of activity is beyond doubt. However, to improve production efficiency, reduce FLW and implement a set of other measures within the framework of the environmental paradigm, this is clearly not enough. Thus, to solve this problem, we cannot limit ourselves to coercive and fiscal measures. It should be cost-effective for entrepreneurs to use scientific developments that reduce the level of environmental impact and FLW. In this regard, it is important to determine which factors will be most effective. Thus, a clear incentive message is needed to implement industrial modernization based on resource-saving technologies.

Obviously, the environmental impact becomes higher the closer to the consumption stage FLW are generated. This is largely due to the process of FLW accumulation at the previous stages of the supply chain. Practice shows that, leaving the production chain, food, as a rule, ends up in landfills, where, under anaerobic conditions of decomposition, gas is released from organic waste, most of which is methane [33].

A similar situation occurs with the generation of waste in animal husbandry. Unfortunately, in some rural areas of Russia, you can still see tons of organic animal waste accumulated near farms. At best, they end up in nearby fields as fertilizer without any transformation. At the same time, many European countries have long had laws prohibiting the use of manure without its appropriate processing [34]. Although manure is a valuable organic fertilizer, however, if it is used improperly, there is a significant negative impact on the environment. Manure becomes especially dangerous if more than 100 tons per day accumulate in one place [35].

Practice shows that it is more difficult for many existing enterprises to move to a new technological level, since the construction of treatment facilities is comparable to the construction of a new farm. Therefore, the area surrounding the old livestock buildings, as a rule, is much polluted. Practice shows that the transition to

[1] Federal Law No. 195-FZ of December 30, 2001 (in the edit December 29, 2022). "The Codex of Administrative Offences of the Russian Federation" Retrieved from https://docs.cntd.ru/document/901807667 Accessed December 27, 2022. (In Russian)

modern technologies requires highly qualified personnel. Its training requires not only a long time, but also additional financial resources [35].

Characteristics of activities concerning FLW in Russia

In a world practice, various approaches and methods are used to solve existing problems related to FLW. In Russia, specialized measures are also being taken to reduce their volume, including in agricultural production, in particular, animal husbandry, and the food industry.

The country has relatively high rates of food loss at several stages of agricultural production and processing. This is due not only to adverse weather conditions, crop pests and animal diseases. Technological and organizational factors also influence, including insufficient technical equipment of agricultural producers [27].

As for the levels of food waste, in Russia they are comparable to those in Europe and North America [28]. The high-risk group, where the loss of food products or raw materials reaches more than 20%, includes the stage of raising livestock and poultry for meat production and the stage of fishing for fisheries, as well as the sale of crop products [4].

According to the data for 2021 of the Federal State Statistics Service of the Russian Federation[2], there is significant food loss in the country at all stages, i.e. from production to sale (Figure 3).

Figure 3. Product loss (thousand tons)

The reason for the formation of significant level of FLW in Russia is a consequence of the existing problems in the production and marketing relationships within the food sector of the agro-industrial complex.

These long-term problems are due to insufficient progress at the legislative level, as well as in research and production activities. This conclusion is supported by several documents. For example, the Strategy for the Development of the Food and Processing Industry of the Russian Federation[3] is focused on the weak material and technical base of many enterprises in this industry. Thus, poor infrastructure for the storage, transportation and refrigeration of perishable raw materials and food does not allow for the complex processing of raw materials and the creation of optimal conditions for their storage. This situation leads to additional product loss and a decrease in its quality.

Therefore, the main solution to this problem is the modernization of equipment and an increase in the extent of raw material processing by involving secondary resources in the economic circulation. These measures will significantly increase the yield of finished products per unit of processed raw materials.

In turn, the Doctrine of Food Security of the Russian Federation[4] also draws attention to the need to develop and implement technical and technological modernization programs in the production of agricultural products, raw materials and food to reduce loss.

In many regions of Russia, a comprehensive infrastructure for the storage and processing of agricultural products has not yet been formed, which causes the need for its rapid sale at reduced prices. In addition, manufacturers often face the problem of low demand for their product. Sufficient storage and refrigeration facilities allows for more flexible planning of supplies at the best market price during periods of high demand and acute stock-out of fresh products [36,37].

Thus, for the successful intensification of the existing process for internal processing of agricultural products, it is necessary to increase raw material storage and refrigeration capacities [38,39], as well as intensify the development of new technologies to reduce loss of agricultural products and increase their shelf life, which will be available to producers even in the most remote regions of Russia [40].

Unlike many countries focused on stimulating waste prevention activities, Russia's economic and environmental policy is more focused on reducing the negative impact of already generated waste and only partial recycling. However, there are norms in Russian legislation declaring a different approach. For example, the Federal Law "About Production and Consumption Waste"[5] indicates the priority areas of state policy in the field of waste management in the following sequence:

[2] Rosstat. Agriculture, hunting and forestry (Balances of food resources). Retrieved from https: https://rosstat.gov.ru/enterprise_economy. Accessed December 27, 2022. (In Russian)

[3] Government Decree of the Russian Federation dated April 17, 2012 No 559-p "Strategy for the development of the food and processing industry of the Russian Federation for the period up to 2020" (as amended on 13 January 13, 2017) Retrieved from https://docs.cntd.ru/document/902343994 Accessed December 27, 2022. (In Russian)

[4] Decree of the President of the Russian Federation No. 20 of January 21, 2020 "The Doctrine of Food Security of the Russian Federation" Retrieved from https://docs.cntd.ru/document/564161398 Accessed December 27, 2022. (In Russian)

[5] Federal Law No. 89-FZ of June 24, 1998 (in the edit December 19, 2022). "About production and consumption waste" Retrieved from https://docs.cntd.ru/document/901711591 Accessed December 27, 2022. (In Russian)

— maximal use of raw materials;
— prevention of waste generation;
— lowering of waste generation and reduction of waste hazard class in the sources of their formation.

Based on the available indicators [41], the food waste amount in the composition of municipal solid waste in Russia is about 35%, which is about 17 million tons per year. Almost the entire food waste (about 90%) ends up in landfills. The specified food waste amount emits about 2.4 million tons of methane. Other gases emitted include ammonia and hydrogen sulfide. Thus, reducing FLW will not only reduce the negative impact on water and land, but will also provide a positive effect in the economics by saving money on the environmental restoration.

The main types of meat raw material loss and the conditions for its formation

According to the studies on the assessment of food loss, at each stage of the value chain in meat livestock husbandry of the Russian Federation [4], it was revealed that the maximum loss of more than 20% to 30% forms the stage of livestock and poultry growing. At the stage of meat raw material processing, loss amounts to 5%; during transportation and storage, loss amounts up to 15%, while during sales it is up to 5%.

The systematization of data on FLW in the EU made it possible to estimate the loss for slaughter animals and poultry along the entire production chain, i.e. from growing to meat consumption, which are presented in Figure 4 [42].

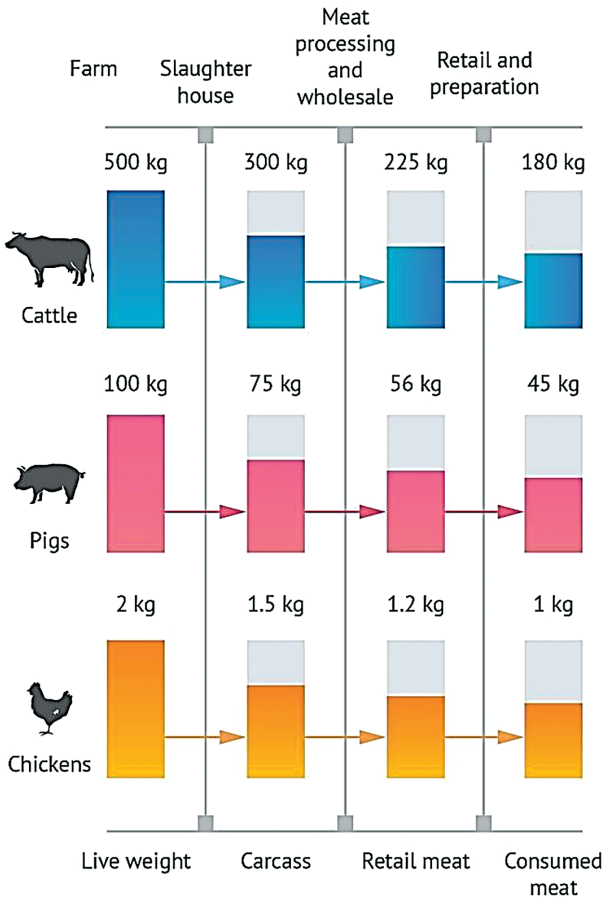

Figure 4. Meat loss (kg)

According to Rosprirodnadzor the data formed on the basis of 2-TP form (waste) of "Information on the generation, processing, disposal, neutralization, transportation and location of production and consumption waste", in the Russian Federation, animal husbandry (meat and dairy) waste amounted to 36.53 million tons in 2017, of which the majority is manure (cattle, pig, horse, etc.), i.e. 68.9%. The key difference between the meat industry and other branches of agriculture is the living nature of the primary raw materials, which imposes certain restrictions on the technological process, since the physical and mental condition of the animal before slaughter directly affects the quality of food products [43].

The main types of loss and the reasons for its occurrence include:

- a significant reduction in the live weight of livestock due to the imperfection of vehicles and pre-slaughter handling of animals;
- veterinary rejection of meat and by-products associated with livestock diseases;
- waste from animal slaughter and carcass butchering;
- low-quality primary processing of livestock;
- decrease in the yield due to the low level of technological support for the processing of raw materials and the sale of by-products (the use of obsolete technologies and equipment);
- defective products in case of violation of technological conditions;
- shrinkage of meat during cooling, freezing and thawing.

Thus, a significant part of loss in meat production is due to the unsatisfactory condition of animals before slaughter, i.e. physical injuries, mental stress, transportation conditions, as well as insufficient use of full-cycle technologies in the processing of raw materials of animal origin.

Also, attention should be paid to meat loss in the process of refrigeration, which is currently still quite high. At the same time, according to some experts, the current industry norms for acceptable loss in this area are maximum permissible and stressful for most enterprises, and it is rather difficult to fully meet them due to the multifactorial nature of the phenomenon. Moreover, there is often excessive loss of meat raw materials and finished products for certain types of food, technological and storage processes, which predetermines the need for special measures to reduce this loss [44].

In this regard, it is worth noting that modern methods and means of controlling temperature conditions in a continuous cold chain of meat and meat products turnover make it possible to ensure the effectiveness of managing these processes at various stages. Temperature measurement and control systems should be aimed at continuous monitoring of the temperature parameters of the environment and the product itself when organizing the processes of its production, storage, transportation and sale. Constant monitoring of temperature regimes allows building an optimal cold chain from producer to consumer,

which reduces risks, maintains the quality and safety of food products sold. Currently, there are opportunities to use various temperature measurement technologies in the implementation of logistical clustering in the supply chain of meat and meat products [45,46].

In this regard, it is worth noting that modern methods and means of controlling temperature conditions in a continuous cold chain of meat and meat products make it possible to ensure the effectiveness of managing these processes at various stages. Temperature measurement and control systems should be aimed at continuous monitoring of the temperature parameters in the environment and product itself when organizing its production, storage, transportation and sale. Continuous temperature monitoring allows building an optimal cold chain from producer to consumer, which reduces risks, maintains the quality and safety of food products sold. Currently, there are opportunities to use various temperature measurement technologies in the implementation of logistical clustering in the supply chain of meat and meat products [45,46].

Possible solutions and practices for FLW prevention and management

Today, most countries of the world implement various initiatives to prevent or reduce FLW, aimed at creating a circular economics, rational use of natural resources, preserving the environment and natural biodiversity, developing sustainable ways of producing, selling and consuming food. The implementation of these strategies should be tailored to the region, with particular attention to local infrastructure, energy, markets and education (i.e. knowledge at all levels from supplier to consumer) [11,12].

To minimize food loss in most countries, the following approaches are used at the government level: consumer education, optimization of post-harvest technologies, increasing the cost of waste disposal, developing partnerships between the private and government sectors to jointly reduce food waste and share responsibility, etc., as well as an approach to modeling and optimizing FLW to support strategies taking into account factors such as inventory management, processing costs, planning and distribution strategies, taking into account the demand from a particular client, etc., since supply chain building is a complex decision-making process in volatility/uncertainty of supply and demand, etc. [47].

Urbanization is one of the causes associated with a large amount of food waste, as it has led to the lengthening of food supply chains to meet the food needs of the population. Therefore, it is important to improve the methods and conditions of storage, transportation and sale in order to avoid loss and waste due to an increase in the distance between the place of production and the place of final consumption [11].

Thus, an important role is assigned to the improvement of logistics in order to reduce FLW. Optimizing supply chain management may help to reduce food waste.

Logistics, as an effective concept for managing material and related financial and information flows, is becoming more and more in demand in the sectors of the agro-industrial complex. The organization of resource supply for agricultural producers and the promotion of their products to the market on the basis of new logistics principles have significant economic, social and environmental effects. Thus, logistics management becomes one of the optimal tools for solving the problem of reducing food loss and waste (FLW), as well as better consumer service.

Such management is the activity of the enterprises that form a well-functioning system of resource supply. In turn, this system is based on the implementation of concentration, distribution and movement of various types of resources and services along optimal pathways to end consumers located in certain territories [48].

According to PLOS Medicine research, up to 80% of the product turnover on the Russian market is occupied by products of transnational corporations (TNCs). Therefore, the issue of storage and intensification of internal processing, as well as reducing the total loss of agricultural products during transportation is acute [38].

Analysis and systematization of research in the field of development and implementation of effective logistics approaches shows their relevance for reducing food loss both at the global and regional levels.

So, the work of Magalhaes et al. [49] used interpretive structural modeling to identify 14 causes of food loss and waste generation in fruit and vegetable supply chains, which were divided into seven levels of influence. The causes of FLW related to logistics were identified, which have a significant impact on the rest causes. The risks of cold chains in pandemics, adaptive strategies for their mitigations and logistical tracking systems, in particular, using various information technologies, are described too [50].

In addition, the nature and causes of FLW along the chain differ in different regions of the world. Evaluation of the results from 24 interviews with key participants in Barcelona made it possible to systematize the causes of food waste in this region of Spain along the entire food supply chain [51]. The results of this study show the great interest of regional participants in the problem of food waste generation and provide a complete map for the causes of their formation according to their level (micro, meso, macro) and their nature (technological, economic and business management, regulatory and policy, appreciation and enhancement). In the article [52], a survey of 47 Belgian enterprises obtained results showing that processing is by far the most important cause of food waste. While transport, changeovers, production interruptions, human error and product exposure at this stage often result in significant or excessive waste, the causes of food loss during packaging, before or after production have less impact. The work [53] is devoted to the analysis of the location of participants and objects of production, transformation, commercial-

ization and distribution, formation of the configuration of the supply chain for perishable foods. It is shown that the improvement in the logistics chain leads to a significant reduction in the loss of perishable food products on the example of Colombia.

In Russia, the existing system of supplies and transportation of agricultural products from the field to the storage and producer needs to be revised. As for agriculture in Russia as a whole, to ensure its dynamic development, the following is necessary [54]:

- connection to the public railway infrastructure with existing terminals and ones under construction, taking into account the capacity of roads adjacent to port and land railway terminals;
- reduction of infrastructure and logistics costs within the vertical supply chain by developing capacities that ensure the storage and transshipment of agricultural products, and reducing the total costs of its shipment, transshipment and transportation by road, railway and water transport;
- implementation of an effective state tariff policy for the transportation of agricultural products by railway, water and road transport;
- improving the efficiency of supply chain management through the use of a more efficient procurement and inventory management model, as well as through process optimization (integrated planning, sales and operations planning);
- reducing loss in the production of agricultural products by reducing equipment downtime (improving aftersales service);
- reducing the cost of logistics operations through the optimization of logistics routes, warehouse network modeling, reengineering of warehouse processes.

Thus, the use of an effective logistics approach in the agro-industrial complex will make it possible to use resources appropriately, reduce time and financial costs at the stage of product delivery from producer to consumer.

The concept of sustainable supply chain management not only helps enterprises to integrate the principles of corporate social responsibility into their activities, but also increases their ability to achieve efficiency in logistics, resource use and FLW reduction [55]. Also, sustainable supply chain management helps to achieve the UN Sustainable Development Goals, in particular the concept of a triple result, which focuses on integrated economic, social and environmental well-being [56].

For perishable foods, such as raw meats and meat products, systematic process and temperature management throughout production, processing and distribution is important to ensure their quality and safety, as well as minimizing waste at all stages of the food supply chain (FSC). This allows food industry operators and technology companies to determine which combination of technologies best fits a given food supply chain and reduces food waste at minimal cost [57].

In recent years, the traceability-based management of cold FSCs has become a popular concept [58]. Traceability requires identifying and recording processing information for all batches of a product in a given process, defined as traceable resource units (TRUs), and exchanging this information as a product (or TRU) moves through the supply chain [58]. Traceability is achieved through the implementation of an information system that includes a wide range of methods and technologies to reduce food loss due to various measures, including accurate stock counting, real-time monitoring of the environment and product conditions, informing about the history and quality of products, and product distribution planning based on expiration date [57].

Spoilage and expiration date on packaging are important causes of food waste, while a significant amount of food is wasted if a sample from a batch does not meet established quality level, resulting in the destruction of the entire product batch. This food loss may be reduced by monitoring food quality throughout the supply chain and using this information effectively. The causes of food loss and waste in middle- and high-income countries are mainly related to consumer behavior, as well as a lack of coordination among the various actors in the supply chain. At these stages of the supply chain (consumer and retail), quality control is difficult to achieve. Appropriate nondestructive methods for quality control of individual products are not available, since most of the methods are too complex or require expensive and complex equipment or materials [59].

Successful action to prevent food loss may be based on the introduction of new packaging technologies that improve the quality, freshness and safety of food or provide a longer shelf life.

Thus, intelligent packaging makes it possible to control the quality of food products throughout the supply chain, as well as at those stages that were previously not subject to control. Various types of intelligent packaging are packaging systems that monitor the condition of packaged foods throughout their life cycle and communicate information related to the quality or safety of the packaged product. The intelligent packaging may contain sensors and/or indicators that monitor product quality or environmental conditions. The information from these sensors must be translated into a meaningful quality indicator that will be passed on to some or all participants in the chain [60]. To do this, the measured signals may be converted by mathematical models into values that reflect the quality of the food product [59].

Currently, the world is exploring the possibility of an integrated approach to increasing the value of FLW as a part of the circular economics development as a solution for waste management [61,62].

The sustainable development of the circular bioeconomics concept is possible only with the introduction of advanced technologies for the valorization of food waste.

Increasing the value of food waste opens up new horizons for economic growth, turning waste into raw materials for biological processes that allow the synthesis of bioproducts from a biological source in a closed cycle. Decomposing food waste to a negative level using advanced technology converts food waste into bio-based products such as biologically active compounds (antioxidants, pigments, polysaccharides, polyphenols, etc.), biofuels (biodiesel, biomethane, biohydrogen), and bioplastics.

FLW may be a useful contribution to the circular economics [62] as a source of bioenergy (biodiesel, biomethane, biohydrogen), and for the production of bio-based products such as biologically active compounds (antioxidants, pigments, polysaccharides, polyphenols, etc.). Agribusiness waste may be used to produce bio-based products, such as bioplastics (food packaging), whose production volume reached almost 1 million tons in 2020, which is almost half of the entire bioplastics market [63].

In a modern world, a linear model of natural resources use ("take — use — throw away") has developed based on the assumption that these resources are abundant, accessible, easy to use and cheap. Solving the issues of efficient use of natural resources, which make it possible to derive economic and environmental benefits from their use, is an important component of the currently formed vision for sustainable development of the world economics. To implement tasks in the field of resource conservation for their efficient use, the transition to a circular economics is of great importance.

The basis of the circular economics is formed by closed supply chains, which are supply chains that ensure the maximization of added value throughout the entire life cycle of a product with dynamic recovery of values and volumes within relatively long time intervals [64]. Ideally, the formation of closed supply chains should lead to the observance of the zero waste principle.

Conclusion

FLW amount, as an example of the extremely wasteful use of food and natural resources, is not only a problem for ensuring global food security and increasing life quality for the world's population.

There is a general consensus on the fact that reducing FLW is a great opportunity to improve food security, ensure the sustainability of food systems and avoid economic costs throughout the food supply chain. But there are significant gaps in knowledge and research on FLW. For example, there is no reliable evidence base for estimating food waste worldwide. In order to effectively assess and optimize strategies and decisions to reduce FLW, the lack of reliable and consistent data and inconsistencies in FLW definitions and measurement systems need to be corrected. Moreover, detailed information about where in the food chain, for which products and in which regions the greatest loss forms must be available, as well as the extent and causes of this problem.

At present time, for most countries it has become obvious that lowering FLW contributes to a more careful use of the planet's resources. Efforts to reduce food loss and waste, which are aimed at more sustainable consumption and production of food, may play a particularly important role in ensuring food and environmental security, solving economic and social problems, increasing the sustainability of value chains both at the regional, federal and international levels.

More comprehensive and integrated approaches should lead to future research on preventing FLW as a part of the circular economics, especially in relation to the socio-economic and environmental impacts of FLW reduction strategies at all stages of the food supply chain in various regional contexts and development conditions considering, among other factors, infrastructure, energy, markets and education.

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The authors declare no conflict of interest.