frontiers | Frontiers in Sustainable Food Systems

TYPE Review
PUBLISHED 10 July 2024
DOI 10.3389/fsufs.2024.1410640

OPEN ACCESS

EDITED BY
Monica Trif,
Centre for Innovative Process Engineering, Germany

REVIEWED BY
Claudia Terezia Socol,
University of Oradea, Romania
Seydi Yikmiş,
Namik Kemal University, Türkiye
Christian Bux,
University of Bari Aldo Moro, Italy

*CORRESPONDENCE
Asem R. Bakhtybekova
asem.alibekova@inbox.ru

RECEIVED 01 April 2024
ACCEPTED 24 June 2024
PUBLISHED 10 July 2024

CITATION
Alibekov RS, Alibekova ZI, Bakhtybekova AR, Taip FS, Urazbayeva KA and Kobzhasarova ZI (2024) Review of the slaughter wastes and the meat by-products recycling opportunities. *Front. Sustain. Food Syst.* 8:1410640. doi: 10.3389/fsufs.2024.1410640

Review of the slaughter wastes and the meat by-products recycling opportunities

Ravshanbek S. Alibekov[1], Zaripa I. Alibekova[1], Asem R. Bakhtybekova[1]*, Farah S. Taip[2], Klara A. Urazbayeva[1] and Ziba I. Kobzhasarova[1]

[1]Food Biotechnology Scientific-Research Laboratory, M. Auezov' South-Kazakhstan University, Shymkent, Kazakhstan, [2]Process and Food Engineering Department, University Putra Malaysia, Selangor, Malaysia

In the ancient times, the Kazakhstan population were considered as nomadic people, where a cult of all types of cattle breeding had a leading position. However, currently the processing approaches of livestock slaughter wastes and secondary meat raw materials are weakly developed. The presented review of waste-free technologies considers the utilization processes of following: carcasses, skins, bones, meat scraps, blood, adipose tissue, horns, feet, hooves, and internal organs. These substances are an important source of animal protein, collagen, bioactive peptides, blood plasma, minerals, and fats that can be applied in various industries: food, feed, medical, and technological. When slaughtering livestock, meat on bones makes up almost half of the total weight of livestock, yet the remaining half contains offal and inedible raw materials. Blood consists of: erythrocytes, leukocytes, platelets, and plasma. Animal bones have mostly proteins (30–50%) and lipids (13–20%) from bone tissues. Tendons, bones and skins contain a large amount of collagen. Animal fat and adipose tissue have 54.9% saturated acids, 40.9% unsaturated fatty acids and 4.2% polyunsaturated fatty acids. Bioactive peptides from collagen derivatives contain from 2 to 20 amino acids and have various biological (antihypertensive, antioxidant, and antimicrobial) activity. This review considers a world current status, modern prospects and opportunities in the slaughter wastes and the meat by-products recycling technologies. Overview of existing approaches for waste processing with the subsequent use of the final product in the food industry, the production of feed, medicines and technical products is considered. The complete processing within the slaughtering livestock and the secondary meat raw materials allows to expand the wide-range products with a low prime cost, thereby promoting to the sustainable development of agroecology by applying the waste hierarchy: Reducing, Reusing, and Recycling.

KEYWORDS
animal, blood, fat, food, processing, product, protein

Introduction

The world population grows every year, since around 6 billion people in 1999 until 8 billion people for 2024. Further 10 billion people will be projected for 2058 (Roser and Ritchie, 2023). Although world hunger has been on the decline for decades, presently, after the COVID-19, there is an increase in the world hunger that affects almost 10% of the world's population (Action Against Hunger, 2024).

This problem was formed not only against the background of a lack of food but also as a result of a lack of financial resources for the purchase of highly nutritious food in sufficient quantities to cover their daily food needs (Grasso et al., 2014; Tastemirova et al., 2022; Alibekov et al., 2023).

The solution to this problem is the integrated development of the agricultural and food industries, as well as the production of high-protein and high-quality food products without industrial waste (Potapov et al., 2017; Alibekov et al., 2019).

One of the fastest-growing sectors of the agricultural industry is animal husbandry, especially in developing countries (Sharma et al., 2021). Livestock production occupies a central place in the development of food systems and is particularly dynamic and complex (Kobzhasarova et al., 2022; Ragasri and Sabumon, 2023). With the growth of the range of animal husbandry, one of the main problems of humanity can be solved, such as reducing poverty and hunger (Alao et al., 2017). Animal husbandry is a very important component of the agricultural economy of developing countries, a contribution (Miller and Lu, 2019) that goes beyond direct food production and includes multi-purpose uses such as the production of hides, animal nutrition, fibers, fertilizers, and fuel, as well as capital accumulation (Chen et al., 2023).

Global demand for meat is growing: over the past 50 years, meat production has more than tripled. The world now produces more than 340 million tons each year. Table 1 shows the comparison of meat production in the Central Asian and some countries, in 1992–2022, includes: cattle, poultry, sheep/mutton, goat and pig. It is noted that for Kazakhstan, in comparison among 1992 and 2022, the meat production is dropped: −17,823.60 tons (Table 1). However, the Kazakhstan population is increased from 17 mln (1992) until 20 million people (2024) (Macrotrends, 2024). In this regard, meat production volume in Kazakhstan is not fully complies for the current consumption.

An improvement of the environmental performance of meat and meat-based products can be obtained by valorizing the animal by-products generated along the meat supply chain that can be used to produce different kinds of products, such as biofuels, fertilizers, animal feed and petfood, biomedical, and cosmetics by reducing the amount of virgin raw materials that would be used for their manufacturing (Ferronato et al., 2021).

However, currently, waste generated during animal slaughter is the cause of inefficient use of food resources and slows down the achievement of food security (Shurson, 2020), which includes providing healthy food to the population, as well as creating a sustainable environmental and economic environment. When slaughtering livestock, almost half of the products are considered inedible by-products. Efficient use and processing of by-products to increase food sustainability in the livestock sector (Alao et al., 2017).

Mostly waste hierarchy consists in: Reduce, Reuse, and Recycle (3 Rs) principles, cleaner production, resource efficiency, zero waste policy. The basic concepts and definitions related to waste management in the EU have been proposed in the Waste Framework Directive, including general rules for the application of end of waste criteria and by-products (Kowalski et al., 2021).

Once a supplier of meat, dairy products, and animal fiber to the Soviet Union, the Central Asian (Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, and Uzbekistan) livestock sector suffered severe reversals following independence. Economic collapse combined with the breakdown of feed supply chains, long distance grazing management and veterinary systems led to plummeting productivity and, in some republics, loss of a large proportion of the national herd (Robinson, 2020).

Kazakhstan is historically a livestock-breeding country. Animal husbandry was the life basis of the Kazakhs and the most important aspect of the life of the nomadic people. Animal husbandry satisfied the nomad's demand for food (meat, milk, and dairy products), clothing (leather, wool) and housing (mat for yurts, felt, etc.). In 2018–2020, the gross output of the livestock industry increased to 23% due to an increase in production in them: meat of all types in slaughter weight—by 10.3%, milk—by 6.4% (USDA Report, 2022). During this reporting period, the number of cattle livestock amounted to 6.8 million heads. Over the past 5–7 years, meat production has increased in Kazakhstan. Beef leads among other types of meat and is 477,000 tons per year, lamb is in second place–150,000 tons per year and horse meat is in third place–126,000 tons per year (USDA Report, 2022). Also, goat meat and camel meat are consumed in Kazakhstan–20,000 and 6.5,000 tons, respectively.

The scheme of specialization of the regions of the Republic of Kazakhstan on the optimal use of agricultural land for the production of specific types of agricultural products is shown in Figure 1 (Konurbayeva et al., 2018; MA of RK, 2022). As can be seen from Figure 1, camels mainly predominate in the desert areas of Western and Southwestern Kazakhstan. In the north of the country, where the vegetation was much richer, horses and cows are bred more. The predominance of sheep is typical for the south of the country.

The change in the slaughter of livestock in live weight in all categories of farms in Kazakhstan is presented in Figure 2 (BNSASPR of RK, 2019). In general, poultry and sheep shares are predominated.

The technological means of the meat industry are constantly evolving to meet the requirements of the present day and may sometimes be inconsistent with ancient religious norms. The halal meat industry is today a reality in many regions of the world, including the European Union. The main religious laws in the area of halal meat production were legislated in ancient times and may be unchangeable due to their sanctity perceived by faithful Muslims, while the modern technology used in the meat industry is constantly evolving and being updated (Abdullah et al., 2019).

Practices of slaughter differ around the world and the degree to which culture and regional interpretations of religion impact consumer expectations and perceptions of suffering at slaughter are relatively unknown. In highly developed countries where exposure to slaughter is low, comfort witnessing slaughter and knowledge about animal welfare at slaughter and the local application of stunning is also low (Sinclair et al., 2023).

Mostly, in the Central Asian countries, including Kazakhstan, on a large scale the halal meat industry is developed (Zheleuova et al., 2021). Figure 3 shows the supply chain of livestock slaughter using the halal blood drip method (Kohilavani et al., 2015; Abdullah et al., 2019). The main distinguishing features of this approach from other methods is that the animal must be suitable for use by Muslim people (1), i.e., not haram, their stunning and rendering

TABLE 1 Comparison of meat production, in 1992–2022, includes: cattle, poultry, sheep/mutton, goat, and pig (Ritchie et al., 2017).

	Country	1992, tons	2022, tons	Absolute change, tons	Relative change, %
1	Kazakhstan	1,258,800.00	1,240,976.40	−17,823.60	−1
2	Uzbekistan	471,115.70	1,348,460.00	+877,344.30	+186
3	Turkmenistan	98,000.00	359,568.72	+261,568.72	+267
4	Kyrgyzstan	227,700.00	256,840.05	+29,140.05	+13
5	Tajikistan	72,800.00	377,983.10	+305,183.10	+419
6	Russia	8,211,761.00	12,244,950.00	+4,033,189.00	+49
7	Germany	6,045,230.00	7,026,647.50	+981,417.50	+16
8	China	34,376,430.00	92,948,520.00	+58,572,090.00	+170
9	India	3,123,220.00	10,644,195.00	+7,520,975.00	+241
10	USA	30,665,134.00	47,530,724.00	+16,865,590.00	+55

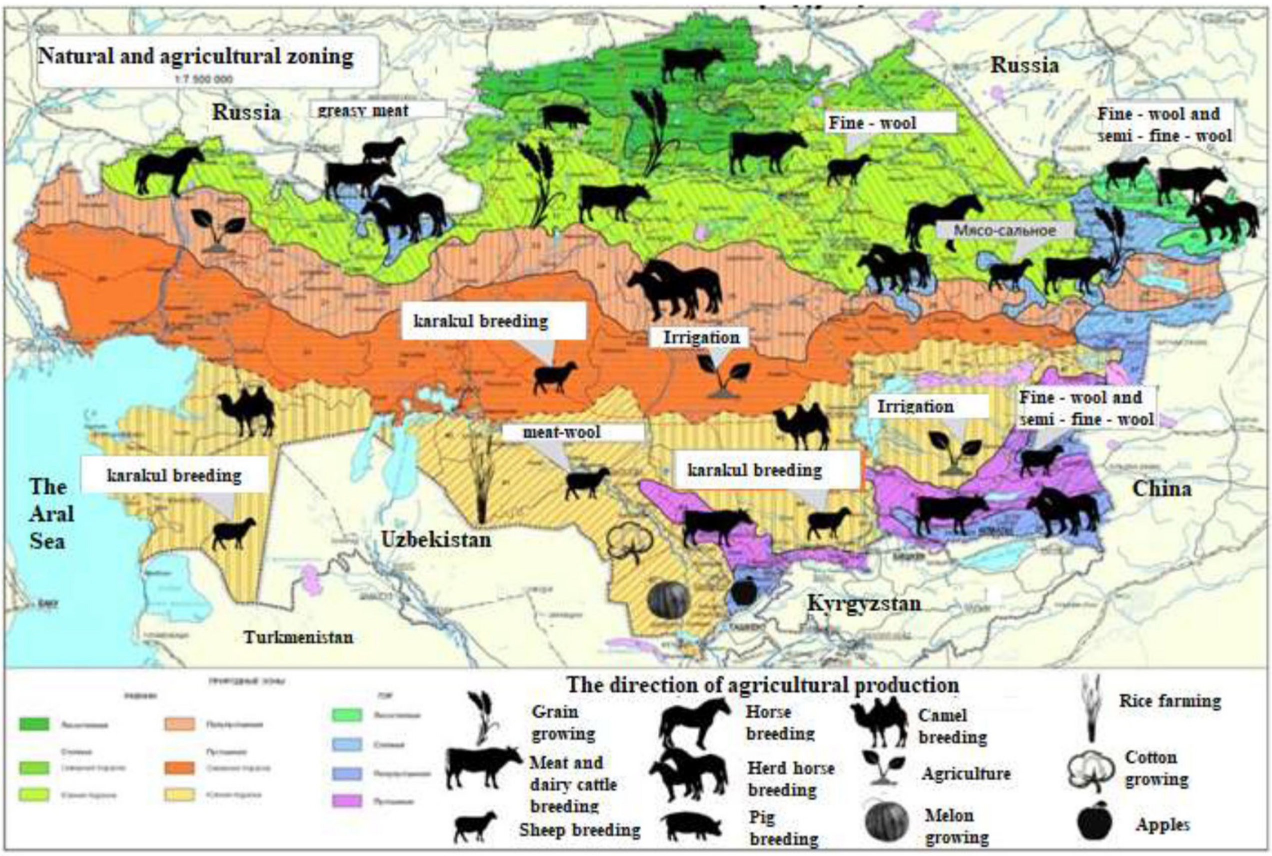

FIGURE 1
Natural and agricultural zoning (Konurbayeva et al., 2018; MA of RK, 2022).

them unconscious is not welcome, i.e., they must be alive (DHCEU, 2024). The main feature is the cutting of the trachea (3) with a sharp knife (2), by a Muslim specialist with sufficient knowledge of Islamic dietary law and food safety. The slaughter should be carried out in the direction from the neck in front (from the chest) to the back (4, 5). In the next step, the animal carcass is cut up. Firstly, the skin, limbs and head of the animal are removed. Secondly, the insides are removed, which are cleaned separately from the carcass. Finally, the entire carcass is washed (6) in contaminated areas and cut up in parts for consumers (7, 8).

By the geographically location, almost half of Kazakhstan's total meat production is concentrated in Almaty, East Kazakhstan and Kostanay regions (Robinson, 2020). More than 60% of meat is produced by private farms. According to preliminary data, 1.06 million tons of meat will be produced in 2022, volumes increased by an average of 0.4% compared to 2021, due to a decrease in

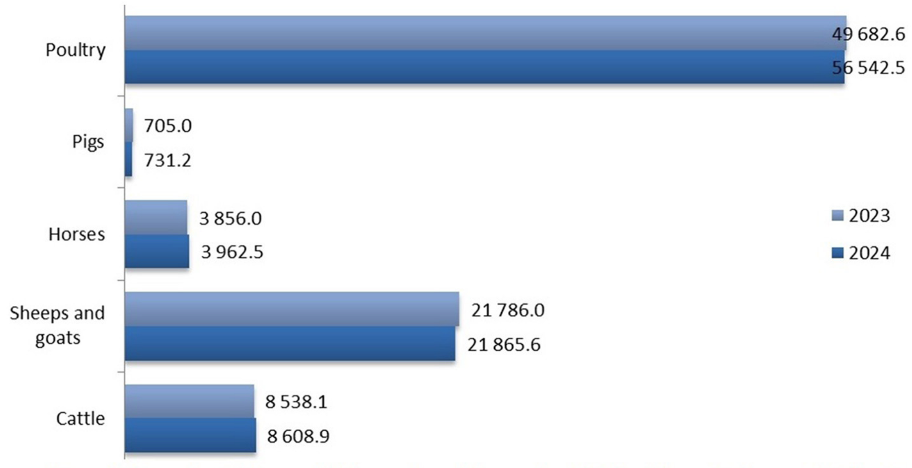

FIGURE 2
Dynamics of changes in the number of farm animals in Kazakhstan.

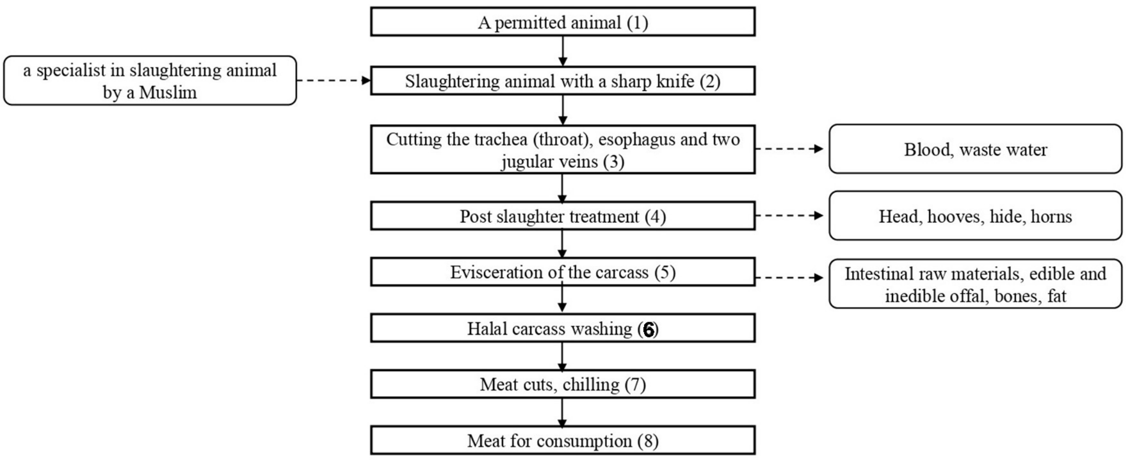

FIGURE 3
Supply chain of halal slaughter of livestock.

production, horsemeat production indicated by 4.3% (MA of RK, 2022).

As can be seen from the above data, Kazakhstan pays great attention to the development of animal husbandry, including meat production. To date, full slaughter technology is carried out in five meat processing enterprises of the Republic of Kazakhstan: Kubley LLP (West Kazakhstan region), Rubikom LLP (Pavlodar region), Semipalatinsk Meat Processing Plant LLP (East Kazakhstan region), Becker and K LLP (Almaty), and "BARON FOOD LLP" (Almaty region; Robinson, 2020). But nevertheless, the issue of recycling of secondary raw materials—skins, blood, bones, and wool of animals remains outside the interests of processing, which are sold for a song or thrown away. At the time when Kazakhstan was part of the "Union of Soviet Socialist Republics" (USSR), all livestock products were processed, for example, hoof oil was obtained, which was used in the rocket industry. France bought the epiphysis, a bone tube that is used for cleaning metals, Japan—a gallstone.

According to the "European Fat Processors and Renders Association" (EFPRA), 328 million livestock and 6 billion birds are slaughtered in the EU every year, resulting in a large number of by-products (Teshnizi et al., 2020; Feliu Alsina and Saguer Hom, 2023). The number of by-products from the meat processing industry reaches 150 million tons. Only a small percentage of these products are used to produce high-value-added products such as animal feed, glue, biofuels, fertilizers, etc. (Javourez et al., 2021). Currently, mainly for the disposal of by-products, the method of disposal in landfills is used, which is the cause of environmental pollution, air, soil and water (Castro-Muñoz et al., 2021). However, these by-products are a rich source of collagen, protein, keratin and minerals (Limeneh et al., 2022).

Currently, in Kazakhstan, the issues of deep processing of secondary raw materials of animal husbandry are relevant, since only skins and wool are currently processed, and it is about 462,000 skins per year, which is about 14% of the total number of skins. About 81% of the skins were left unprocessed, as a result, the state

TABLE 2 The number of sheep in Central Asian countries.

Countries	2000 year	2007 year	2022–2023 years
Kazakhstan	8,725,400	12,813,700	23,000,000 (Skokov and Dyussegalieva, 2023)
Kyrgyzstan	3,263,830	3,197,067	6,200,961 (NSC of KR, 2022)
Tadjikistan	1,472,200	1,955,200	6,300,000 (WPR, 2024)
Turkmenistan	7,500,000	15,500,000	15,400,000 (WPR, 2024)
Uzbekistan	8,000,000	10,383,000	20,600,000 (WPR, 2024)

annually loses more than 6 million USD. There are 21 enterprises processing hides and wool in the country, the workload of the first is 27%, the second is 13%. While in Europe, 18 million tons of raw materials of animal origin are processed annually to make them safe and stable (Jedrejek et al., 2016). The meat industry generates a significant amount of hazardous waste, containing phosphorus, calcium, and other elements which could be the basis for other products (Kowalski et al., 2021).

The Central Asian countries were engaged in animal husbandry since historical times. Central Asia has 11.24 ha of pastures per livestock farm. Table 2 shows data on the number of sheep in Central Asian countries for different periods. As can be seen from the Table 2, the number of sheep is growing every year, but nevertheless, the waste from slaughtering livestock that could be recycled to produce processed products is also growing. As in Kazakhstan, but also in all Central Asian countries, the issue of processing slaughter products is acute.

Turkmenistan is the leader in the number of livestock after Kazakhstan (Robinson, 2020). As of 2022, the number of cattle in Turkmenistan amounted to 2,494.0 thousand heads (CAN, 2023). However, there is no data on processed products at the slaughter of livestock.

Uzbekistan is one of the developing countries in Central Asia. According to the State Statistics Committee, the total number of cattle in the republic as of April 1, 2022 reached 13,311.3 thousand heads (SAP of RU, 2023). At the same time, the number of livestock per Uzbekistan residents has increased by 10.8% over the past 5 years. The number of cattle is 12.4 million, sheep and goats–20.7 million, poultry–71.3 million. Currently, Uzbekistan has the first and only facility zero-waste enterprise in Eurasia—the "UZGEN technological meat processing plant," in Jizzakh (UZGEN TMPP, 2023).

One of the most valuable by-product of animal husbandry is the blood of slaughtered cattle. The blood obtained at the slaughterhouse can be used in different ways, and its use depends on local customs, rules and production practices (Nwogor et al., 2015). Some common uses of blood in the slaughter process include: food products (emulsifiers, stabilizers, clarifiers, food additives, egg albumin substitutes, and addition to meat products), animal feed, medicines, etc. (Rohman et al., 2021). All feeds prepared from waste and by-products of processing of farm animals and poultry are classified as protein concentrates, they are rich in minerals, are well-digested, and are mainly used to enrich livestock diets (Martínez-Alvarez et al., 2015; Ercen et al., 2022). Animal feed plays an important role in providing essential amino acids to maintain the high productivity of animals and improve the quality of meat. A decisive role in the development of the feed reserve is assigned to the creation of new feed additives (Day et al., 2022).

One-fourth of the total volume of livestock is made up of bones, which are also not processed in sufficient quantities, but are a rich source of protein, calcium, phosphorus, and other vitamins useful for animal growth when used in feed. Among the secondary resources of livestock and poultry processing, sources of collagen are of particular interest, which accounts for from 25 to 33% of the total mass of proteins of slaughtered animals with connective tissue leaving 16% of the mass of meat on bones (Jayathilakan et al., 2012). In the food industry, there is a great demand for collagen and gelatin due to their high protein content and their functional properties, such as water absorption, gelation, and the ability to form and stabilize emulsions (Schmidt et al., 2016).

Trends in the field of industrial food production are associated with the creation of an assortment of functional products (Zakharova, 2014) that contribute to the maintenance and correction of health during their daily consumption due to the regulatory and normalizing effects on the body as a whole or on certain organs or functions (Shingisov et al., 2016). A special role here belongs to secondary products of cutting and processing of farm animals and poultry, as sources of biopolymers and their essential structural units—essential amino acids, polyunsaturated fatty acids, organic iron, and other macro- and micronutrients (Ravi et al., 2020).

The use of the above-mentioned modern technologies and innovations contributes to the intensification of waste-free technological processes, as well as to increase efficiency and improve the quality of finished products (Satayev et al., 2012). Based on this, it is relevant to study the issue of integrated use of all types of livestock products. The novelty of the author's work is an integrated approach to the study of the problem of the integrated use of the raw materials obtained during the slaughter of livestock, instead of its full and deep processing.

The work's objective is to review waste-free technologies in the complex processing of inedible components from the raw materials of livestock slaughter by producing useful products. It can be divided into several sections:

1. Overview of primary and secondary raw materials in the meat industry.
2. Analysis on Animal blood treatment technologies opportunities.
3. Evaluation on different Animal bones processing approaches.
4. Review of Secondary collagen-containing raw materials applications.
5. Animal fat and adipose tissue processing technologies.

Methodology

Mostly, for the selecting of bibliographic databases, following search engines were used: Web of Science, Scopus, PubMed, Science Direct, and Google Scholar. In the interest of simplification, the initially data collection of the related text words contained in the title and abstract was analyzed. At the next search, all identified keywords and appropriate indicators was reviewed. Finally, the reference lists of all acceptable material including original and review papers, book chapters, electronic sources, and publications were considered. Moreover, the relevant information was evaluated and collected.

Primary and secondary raw materials in the meat industry

Two main materials are obtained at slaughterhouse: halfcarcasses and by-products. If the half-carcasses are considered as homogeneous material, then the by-products can be divided into different subcategories, with different opportunities for valorization or disposal, as follows: inedible offal; skin; edible products; blood; other by-products are intended for mandatory incineration (Amicarelli et al., 2021).

In the process of slaughtering livestock, also, processing slaughter products, 45% of meat on bones and 55% of by-products and non-food raw materials are obtained. Several secondary raw materials include by-products not directed to food as the main raw material: intestines, blood (food and technical), bone, hides, raw fat, endocrine-enzyme, and special substances, contents of the gastrointestinal tract, and non-food raw materials (Table 3; Denissova et al., 2021). All of them is used for the manufacture of certain types of food products, pharmaceuticals, feed and technical goods, leather, fur products, and others.

As can be seen from Table 3, the largest average volume of secondary raw materials of cattle is the contents of the gastrointestinal tract (16.8%), non-food raw materials (12.2%), bones (9.5%), and the lowest weight is endocrine-enzyme raw materials (0.4%; Denissova et al., 2021).

TABLE 3 The volume of formation of slaughter products (Denissova et al., 2021).

Name of raw materials	Cattle	Small cattle
	%	
Meat on bones	45	38
Meat	35.5	28.8
Bones	9.5	9.2
By-products	10.4	7.8
Guts	2	2.3
Skins	7	10
Raw fat	3.1	1.9
Blood:	3.1	3.2
Food	1.5	–
Technical	1.6	3.2
Endocrine-enzyme raw materials	0.4	0.6
Contents of the gastrointestinal tract	16.8	23.5
Non-food raw materials	12.2	12.7
Slaughter weight	58.5	47.7

Within processing of small cattle, the yield of meat on bones and offal is 18.32 and 33.33% less than that of large cattle. However, the contents of the gastrointestinal tract are 28.51% larger. The resulting secondary raw materials are processed for such industries as food, fodder, medical, and technical (Figure 4; Denissova et al., 2021).

Further from Figure 4, such products as by-products, raw fat, and blood are highly valuable products for fodder production and the food industry. Bones can be used for food purposes in the production of dry concentrates for livestock and poultry feed. It is determined that the quality of the obtained meat products is influenced by the methods of slaughtering livestock (Bakhsh et al., 2018).

Animal by-products (Galanakis, 2018) can be defined as whole bodies or parts of slaughtered cattle, as well as other products obtained from animals that can, but are not intended for direct human consumption. The division of offal depends on several factors, including: traditions, society, and religion, but for the most part, they are recognized as carcasses, skins, bones, meat scraps, blood, adipose tissue, horns, feet, hooves, and internal organs. Meat offal has nutritional value by lipids, carbohydrates and proteins.

Depending on the use for food purposes, offal is divided into red and white (Huygens et al., 2019; Abdilova et al., 2021; Shirsath and Henchion, 2021) Red by-products such as liver, heart, kidneys, and tongue are usually edible after they are cooked. Stomachs, and intestines are classified as white by-products, and require additional processing before use (Shirsath and Henchion, 2021).

For technical purposes (animal feed), it is allowed to send the spleen, sheep heads, and legs. Food by-products are divided into edible and non-edible (Figure 5; Alao et al., 2017).

The slaughter process of livestock begins with the stunning of livestock that are divided into electric stunning, mechanical stunning and gas anesthesia. The common method is electric damping, the advantage of which is a minimum of effort and time. The disadvantage is the likelihood of local outpourings of blood and the hardness of meat. By the mechanical method, the quality of meat and offal is much higher. The gas method is mainly used for pigs. Also, the rules for slaughtering cattle differ by national and religious characteristics (Riaz et al., 2021). For example, in halal slaughter, which is often practiced in Kazakhstan, cattle stunning is not used, on the contrary, the animal's throat is immediately cut with a knife.

The technologies of butchering carcasses for large and small cattle are different. In large animals such as cows, bulls and horses, the carcass is cut along the middle line of the breast bone, preventing damage to edible and inedible offal. At that time, the rectum is cut out in sheeps and goats, after that the gastrointestinal tract is removed from the abdominal cavity (Riaz et al., 2021).

As follows from Figure 5, non-edible by-products are mainly used in the production of animal feed, medicinal products and food products.

Thus, during of slaughtering livestock, 45 % of meat on bones and 55 % of by-products and non-food raw materials are obtained. At the full processing, carcasses, skins, bones, meat scraps, blood, adipose tissue, horns, feet, hooves, and internal organs have nutritional and technical values.

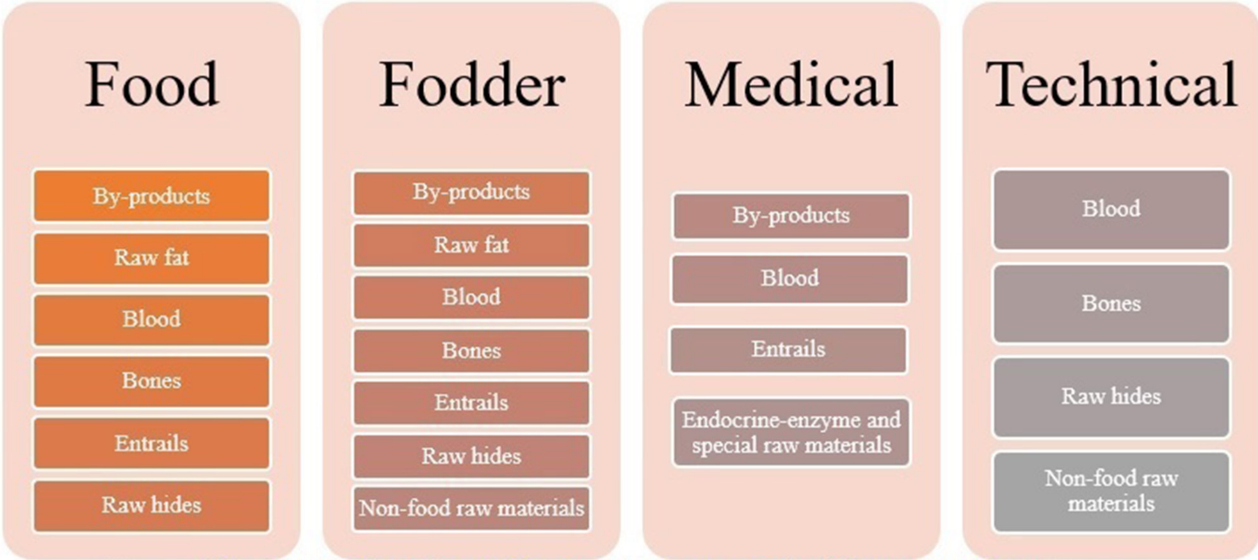

FIGURE 4
Directions for the secondary raw materials recycling.

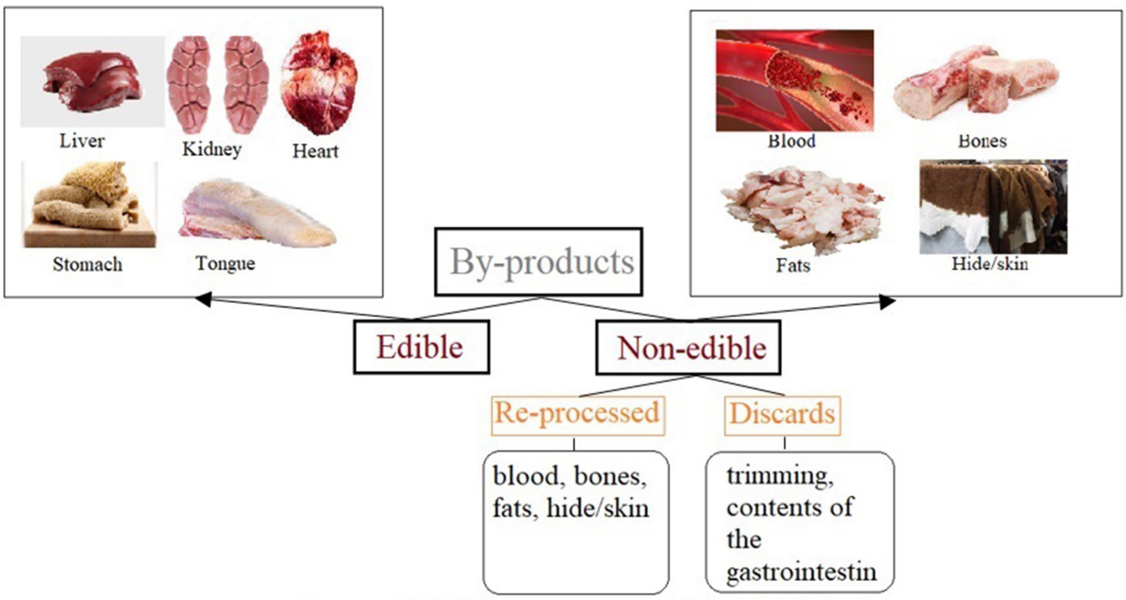

FIGURE 5
Edible and non-edible by-products.

Animal blood treatment technologies opportunities

The product of secondary raw materials of animal husbandry is a unique source of nutrients and biologically active substances, including high-value protein and organic iron (Ofori and Hsieh, 2014; Aung et al., 2023). The range of applications of waste blood is wide (Leoci, 2014; Helkar et al., 2016), for example, blood products are used for food, technical, feed, and therapeutic purposes (Figure 6).

For food purposes, blood is used as an emulsifier, stabilizer, clarifier, coloring additive, and as nutritional component (Bahru, 2021). Bier et al. (2014) noted that in the food industry, about 30% of the total blood volume is used as gelling agents and natural dyes.

One of the most valuable products is blood meal, which is an insoluble dried blood powder containing at least 80% protein, 3% fat, 6% ash, and less 10% moisture. Natural proteins are linear, unbranched, and of precise length with a molecular diversity consisting of 20 different amino acids as monomers. Beef blood flour contains more lysine, valine, threonine, leucine, tyrosine, and

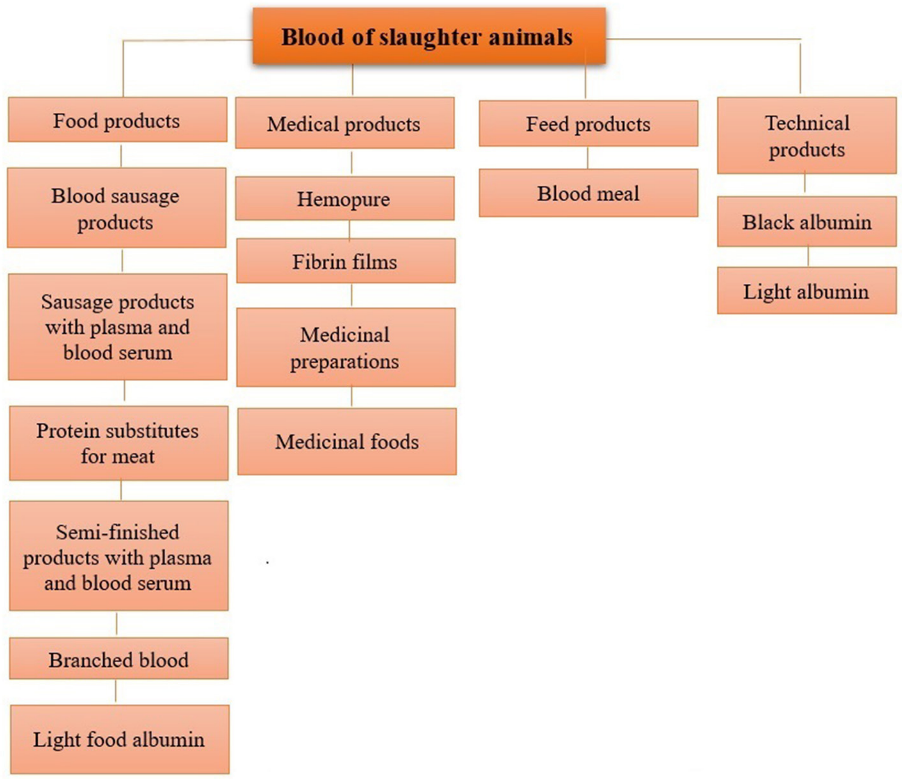

FIGURE 6
Application of waste blood.

phenylalanine, while pork blood flour contains more histidine, arginine, proline, glycine, and isoleucine (Hicks and Verbeek, 2016; Day et al., 2022).

Blood consists of four components: erythrocytes, leukocytes, platelets, and plasma. The expediency of separate processing of blood fractions in the form of plasma and shaped elements has been scientifically and experimentally proved (Aung et al., 2023). Plasma products are mainly used in the meat industry, they are also used in other branches of the food industry. For example, (Bah et al., 2016) spray-dried plasma can be used as an egg substitute in bakery products due to the foaming and leavening properties of blood plasma proteins.

Composition and properties of blood

Blood consists of a liquid part—plasma and shaped elements suspended in it. The blood plasma contains proteins, glucose, lipids (fats, lecithin, cholesterol, etc.), lactic and pyruvic acids, amino acids, urea, uric acid, creatine, mineral salts, enzymes, hormones, vitamins, and pigments (Bah et al., 2013; Oh et al., 2023).

The density of blood is 1,055 kg/m^3, plasma 1,027... 1,034 kg/m^3, erythrocytes 1,080... 1,090, fibrin 700... 800, and serum 1,024 kg/m^3. Since red blood cells are heavier than plasma, they can settle in it. The separation of shaped elements from plasma by settling, centrifugation, and separation of blood is based on this property (Al-Mahmood and Fraser, 2023).

Blood treatment, the use of blood meal in animal feed

Blood products are obtained only from healthy animals that have passed a veterinary examination.

There are open and closed ways of collecting food and blood. The authors of the work, based on epidemiological data, found that improperly organized slaughter of animals can lead to infection of meat with pathogens of food origin (for example, *Salmonella bacteria*; Bobbo et al., 2017; Cetin et al., 2020).

With a closed method of collecting food blood, the necessary completeness of collection and high sanitary and hygienic conditions are provided (Boma et al., 2022).

The processing scheme of blood is shown in Figure 7. The first stage after collecting the blood of slaughtered animals is the stabilization process. This procedure is carried out to prevent blood clotting, preserve a valuable product such as fibrinogen, as well as increase the yield of finished products. For this purpose, aqueous solutions of phosphoric acid salts (sodium tripolyphosphate, sodium pyrophosphate, and nine-water trisodium phosphate) and sodium citrate are used. The blood used in sausage production in its entirety is stabilized with table salt, and the blood intended for separation is not allowed to be stabilized with table salt, since at the same time there is strong hemolysis.

After the stabilization process, the blood enters the defibrillator to release the blood from fibrin. The purpose of defibrillation is to avoid rapid blood clotting (Giu and Giu, 2010; Nazifa et al., 2021).

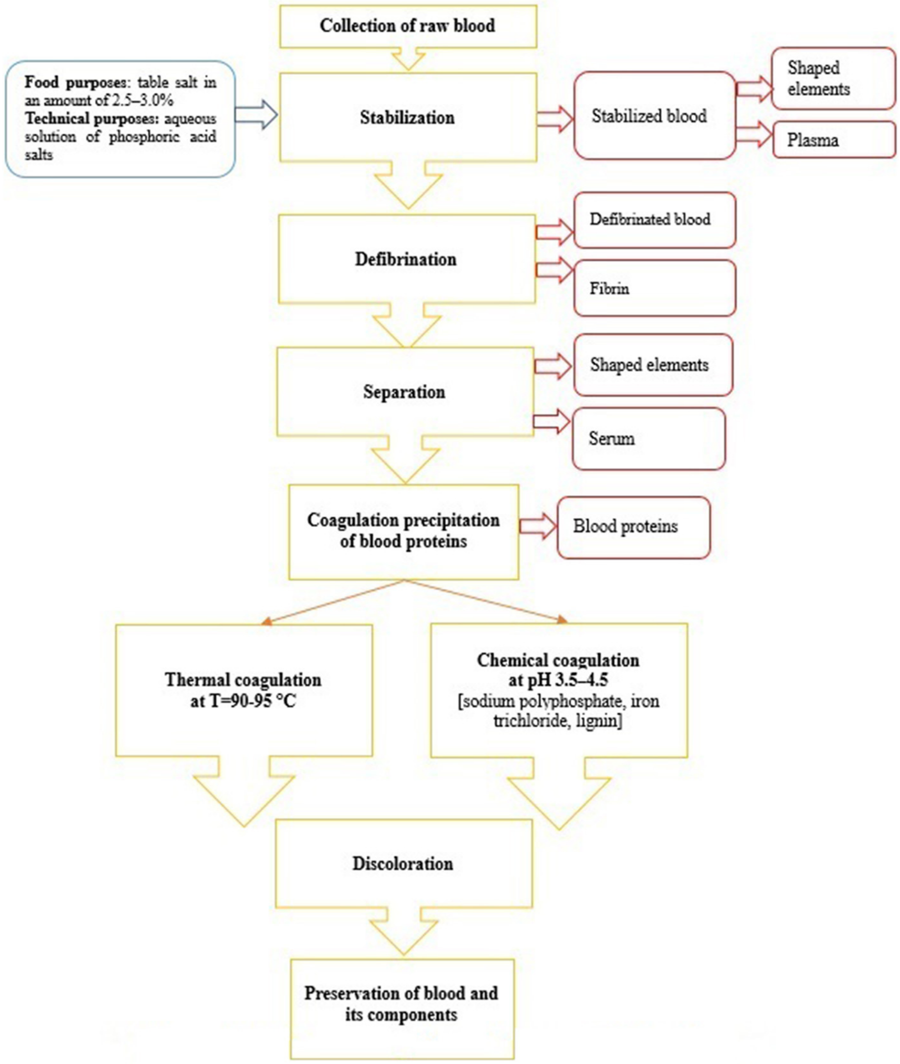

FIGURE 7
Processing scheme of blood.

The separation of the blood of slaughtered animals into fractions contributes to the most rational use of it. The separation method used for this is based on the fact that the shaped elements have a higher density compared to blood plasma (serum).

To obtain high-quality blood proteins, coagulation precipitation is carried out. There is thermal and chemical coagulation of proteins. Thermal coagulation is carried out at the temperature of 90–95°C to significantly reduce the mass fraction of moisture in the coagulate (up to 50%) and its microbiological contamination. The disadvantage of thermal coagulation is the partial loss of native (natural) properties of blood proteins, due to their denaturation. Chemical coagulation of blood proteins and their fractions is carried out in an acidic environment at a pH of 3.5–4.5, as well as coagulants (for example, sodium polyphosphate, iron trichloride, lignin, and its derivatives). At the same time, up to 98% of proteins are deposited, and their denaturation, as a rule, is expressed to a lesser degree, compared with thermal coagulation (Lynch et al., 2017).

The use of blood for food production is limited by the fact that it gives products a dark color when added even in small quantities. In this regard, the blood is discolored. Bleaching of blood is carried out by several methods. Chemical methods are based on the removal of heme from the hemoglobin molecule. One of them provides for the separation of heme in an acidic environment in the presence of acetone (Hopp et al., 2020).

Drying of blood and blood products ensures their long-term preservation in conditions of unregulated temperature and significantly facilitates their transportation. Spray drying of blood has become the most widespread. This process consists of three successive stages: spraying the liquid with a thin layer, drying it in a current of heated air, and separating the particles of the dried material from the air. To increase the efficiency of spray drying, the solution is pre-concentrated (evaporated) and the heat of the exhaust air is reused (Sharma et al., 2014).

Also in practice, there is an invention according to which microorganisms are used to decompose waste animal blood and obtain high-quality environmentally friendly amino acids, thereby ensuring the effect of recycling resources and preventing environmental pollution (Pinto et al., 2022). The authors of the invention used various microorganisms to obtain valuable amino acids, as a mixture of *Bacillus subtilis* and *Bacillus natto* microorganisms, for the decomposition of lipids, and *Cellulomonas cellulans* were used as microorganisms decomposing cellulose. Also, *Pseudomonas aeruginosa* or *Rhodopseudomonas gelatinosa* are used as microorganisms decomposing carbohydrates, and *Nitrosomonas europaea* or *Nitrobacter winogradski* are used as nitrifying microorganisms (Ruiz Sella et al., 2021). Adequate thermal processing is effective for inactivating all biological agents of concern, perhaps except for prions from infected ruminant tissues (Shurson, 2020).

Before feeding animals, blood meal must be heated to a minimum temperature of 100°C for 15 min to destroy potential pathogens (*Salmonella*, mycotoxins, and prions; Seifdavati et al., 2008; Ricke et al., 2017). Since blood meal is a high-protein product, it can be replaced with a fish meal in the diet of broiler chickens. An interesting result obtained by the authors (Swe et al., 2022) is that the blood meal of purchased cattle is a suitable substitute for dietary fish meal, and a complete replacement did not have any adverse effect on productivity, on the contrary, the daily weight gain of chickens was significantly increased and the cost of producing a unit of meat was reduced.

There are also experimental results of feeding blood meal (Navarro et al., 2018) of various concentrations to pigs. It was found that when using five dietary concentrations of blood meal (0.3, 0.5, 9, 8.9, and 11.8%), pigs receiving 5.9 or 8.9% of blood meal grew more efficiently than pigs receiving 0 or 11.8%.

The results of the experiments show that blood meal has a huge impact on the amount of milk in a dairy cow. The authors of the work (Ipharraguerre and Clark, 2005) obtained results that a mixture of feathers and blood improves the production of milk protein when added to the diet. The authors of the work (Helkar et al., 2016) found that cows fed with animal protein produced 3.5% more milk, fat, and true protein adjusted for fat content than cows fed with vegetable protein.

The authors of the work conducted studies to study the effect of oil palm leaves as an absorbent of blood meal and the fermentation process using various inoculants as ingredients of feed for ruminants. It was found that fermentation of blood meal with absorbent palm oil leaves using *Lactobacillus plantarum* inoculant with an incubation time of 120 days showed positive results (Imsya, 2022).

Obtaining various functional products and medical preparations from the blood of cattle

The blood of cattle, in addition to animal feed, is also used in the production of medicines and food. One of the medicines manufactured on the basis of cattle blood is Hemopur. Hemopur is a chemically stabilized, bovine hemoglobin dissolved in a saline solution intended for human use, which was developed by Biopure Corporation (Cambridge, Massachusetts, USA; Chen et al., 2023). During the production process, hemoglobin is crosslinked and polymerized by reaction with glutaraldehyde under fully automated conditions.

Fibrin films are also obtained from the blood of cattle by stabilizing with sodium citric acid, which are used as a plastic material for burns, poorly healing wounds and ulcers (Toldrá et al., 2023).

In the food industry, blood is used as a binding additive, color enhancer and dye, emulsifier, fat substitute, and meat curing agent (Alao et al., 2017).

Hemoglobin, an iron-rich protein that is part of the blood of cattle, is a good source of natural red dye. Emulsifiers obtained from the blood of cattle help to thinly distribute fat throughout the product, which results in the correct texture in emulsified meat products such as sausages, pates, meat semi-finished products, and mortadella. Fat substitutes derived from cattle blood protein can potentially replace fat in meat products, while reducing the caloric content of food for each gram of replaced fat (Ofori and Hsieh, 2014; Ismail et al., 2020).

Whole animal blood is traditionally used in Europe and Asia in products such as blood sausage, blood pudding and blood pie (Ofori and Hsieh, 2014; Anjos et al., 2019; Thi et al., 2023).

Thus, blood products are used for food, technical, feed and therapeutic purposes. Blood consists of two main components: plasma and shaped elements suspended in it (erythrocytes, leukocytes, and platelets). The blood plasma contains proteins, glucose, lipids, enzymes, hormones, and other significant compounds. Various blood treatment approaches allow for the obtaining hemoglobin and essential amino acids. Blood meal is used as additive for the animal feed, also emulsifier, natural dye, and functional ingredient for food purpose (Hsieh and Ofori, 2011; Imsya, 2022).

Animal bones processing approaches

The bones of slaughtered animals are used to produce edible fats, broths, etc., as well as raw materials for technical purposes—for the production of small consumer goods, as well as bone glue, meal, and coal. The mammalian skeleton consists of a large number of individual bones (Kim et al., 2014, 2017).

The poultry industry shows a significant difference compared to other meat industries (e.g., pork and beef) where an additional deboning occurs at retail and slaughterhouse, considering that whole chickens, as well as chicken wings and thighs, are usually sold and consumed at households with bones, so-called “meat on the bone” or “bone-in meat” (Bux and Amicarelli, 2022).

The thermal utilization (at T = 900–1,000°C) of bone meat waste allows to apply of the obtained hydroxyapatite ash as a substitute for phosphorus raw materials. The high-quality hydroxyapatite ash could be used for the production of food grade phosphoric acid and also for the production of food grade mono- and dicalcium feed phosphates (Kowalski et al., 2021).

One of the methods for obtaining bone meal consists of the following steps (Figure 8).

There are three grades, the highest, the first, corresponds to the minimum percentages of moisture, fat, and ash, and the maximum amount of protein. The main components of meat and bone meal

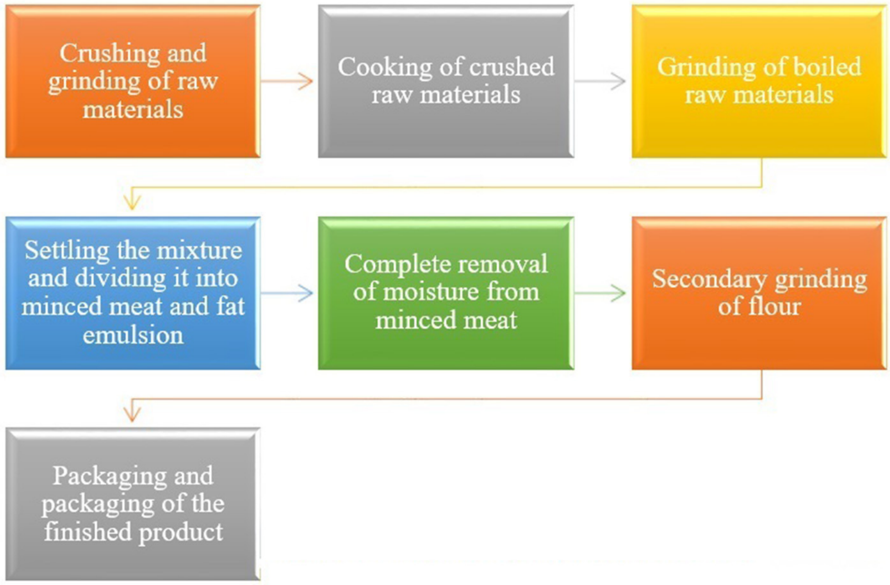

FIGURE 8
The methods for bone meal obtaining.

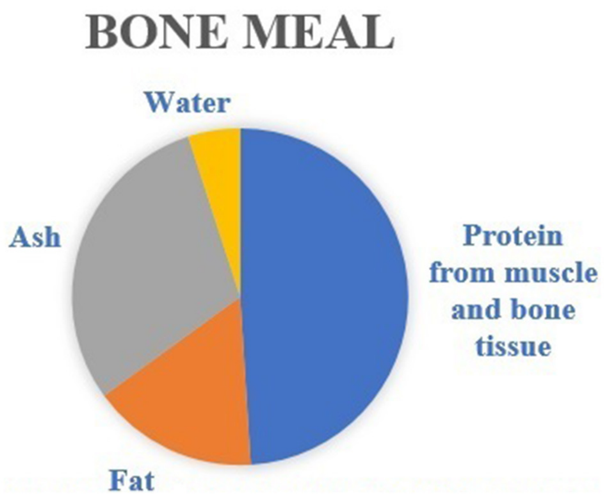

FIGURE 9
The main components of bone meal.

(Galanakis, 2018): are protein from muscle and bone tissue (from 30 to 50%), fat (from 13 to 20%) ash (from 26 to 38%), and water (up to 7%; Figure 9).

Kim et al. (2017) investigated the effect of the slaughter age (28, 32, or 38 month) on the approximate bone composition, fatty acid composition, collagen content, amino acid and mineral content in horse leg bone extracts. It was determined that the content of palmitoleic acid and essential fatty acids, as well as amino acids, in the bones of the slaughter at 38 months is higher than in 28 and 32 months.

It is known that bone meal is an excellent alternative to fish meal in the aquaculture industry. The authors (Ai et al., 2006) conducted experiments on cultivation to study the effect of replacing fish meal (FM) with meat and bone meal (BM) in the diet on the growth and body composition of the large yellow humpback (*Pseudosciaena crocea*). It was determined that from the developed six isonitrogenous (43% crude protein) and isoenergetic (20 kJg^{-1}) diets replacing 0, 15, 30, 45, 60, and 75% of FM protein with BM protein, 45% of FM protein can be replaced with MBM protein in the diet of the big yellow humpback without a significant decrease in growth. The authors of the following work (Woodgate et al., 2022) conducted a test to evaluate the replacement of fish meal (FM) with meat and bone meal (BM; 53% CP, 15% CL, 27% Ash) in the diets of juvenile golden-headed sea bass (Sparus aurata). From the point of view of economic efficiency, rations using BM led to a reduction in production costs with the lowest economic conversion factor.

There are also studies on the analysis of the efficiency of the production of bioethanol and biodiesel obtained from corn grain fertilized with meat and bone meal obtained from animal waste. A positive effect of meat and bone meal on the yield of bioethanol from grain due to an increased starch content was found (Stepień and Rejmer, 2022).

Thus, animal bones have mostly proteins (30–50%) and lipids (13–20%) from bone tissues (Galanakis, 2018). Bones are used in the production of edible fats, broths, functional additives, etc., as well as for the technical purposes: bone glue, meal, coal etc.

Secondary collagen-containing raw materials applications

Significant value has by-products of 2nd category that rich in connective tissue proteins and especially collagen. Despite of the scars containing 6.8% of collagen from the raw tissues mass, it can be noted tendons, in which 87.6% of the mass of total proteins is represented by collagen of the ears and noses, containing 72 and 52% of collagen from the sum of all proteins, respectively. Collagen is a protein that is the main structural component in the vertebrate body, which accounts for about 1/3 of the mass of all proteins (Sherman et al., 2015; Fu et al., 2016).

The basis of the structural organization of the collagen fiber consists of stepwise parallel rows of tropocollagen molecules oriented in the longitudinal and transverse directions and shifted by a quarter, which causes the transverse striation of the fibrils (Nimni and Harkness, 2018).

Gelatin is obtained from fresh raw materials (skins), which are in an edible state by controlled hydrolysis of water-insoluble collagen. Skins, along with bones, contain a large amount of collagen. Obtaining gelatin from skins and bones includes the removal of uncollagenized material from raw materials, controlled hydrolysis of collagen to gelatin, and extraction with subsequent drying of the final product (Ai et al., 2006; Sherman et al., 2015). The authors extracted gelatin from bovine skin using the plant enzymes bromelain (B) and zingibain (Z). Only blurred bands were observed in GEZ gelatins, while GEB samples revealed the presence of low molecular weight polypeptides (Ahmad et al., 2020).

A characteristic feature of the chemical and morphological composition of the by-products of the second category of cattle is the complexity and heterogeneity of their structure. The fat–products of the second categories of cattle consist mainly of neutral fats with a large amount of fat-like substances—phosphatides, cholesterol, and cerebrosides (Ai et al., 2006).

A promising direction of using secondary collagen-containing raw materials for food purposes is to obtain hydrolysates or protein preparations from them (Table 4).

One of the promising applications is protein hydrolysate as fertilizer for plants. Protein hydrolysates have attracted attention to their use in agriculture because they have been proven to be effective in increasing soil fertility (Da Silva, 2018).

It has also been established that collagen derivatives obtained by enzymatic hydrolysis of collagen–containing cattle raw materials—low-molecular-weight collagen peptides—have new functional properties and have a number of advantages over high-molecular-weight starting components. Bioactive peptides contain from 2 to 20 amino acids and have various biological (antihypertensive, antioxidant, and antimicrobial) activity. However, in the initial version, they are located in the protein and are inactive. Biotechnological methods such as hydrolysis and microbiological fermentation are used to produce peptides (Cruz-Casas et al., 2021). Nevertheless, with the development of new technologies, there is growing interest in the production of bioactive peptides using new technologies such as HHP, ultrasound, pulsed electric field, microwave oven and subcritical hydrolysis of water (Mora and Toldrá, 2022). There are also results on the use of the latest method—steam explosion (SE) collagen peptides extracted from cattle bones. It was determined that steam does not affect the amino acid composition of collagen peptides (Zhang et al., 2023). In the course of experimental studies, it was determined that papain is the most effective in obtaining ACE-inhibitory peptides (Fu et al., 2018).

It is also known that using enzymatic hydrolysis with a Box-Benken design with the addition of Flavourzyme and Protamex, antioxidant peptides were obtained from bovine bone extract. An interesting fact is the identification of two peptides Ala-Pro-Phe with a mass of 333.12 Da and Asp-His-Val with a mass of 369.14 Da, which can play a significant role in antioxidant capacity (Begum et al., 2024).

It is known, secondary collagen-containing raw materials were fermented in the development of a technology for the production of combined sausage meat products, by using a consortium of microorganisms, consisting of the following cultures: *Lactobacillus bulgaricus*, *Bifidumbacterium siccum*, and *Staphilococcus carnosus*. As a result, the positive effect of the proposed biotechnological method for processing meat raw materials on the organoleptic, physicochemical, structural-mechanical, microbiological characteristics, and biological value of the final product was discovered (Gizatova et al., 2021).

There is also a study on the use of a collagen preparation based on offal of the second category (lips and ears of cattle) in the production technology of egg white cream. It was found that egg whites with the addition of 5% collagen preparation showed their high functional and technological properties (Lukin, 2018).

Thus, tendons, bones and skins contain a large amount of collagen. Collagen accounts about 30% of the mass of all proteins (Sherman et al., 2015). Obtained by enzymatic hydrolysis of collagen derivatives, low-molecular-weight collagen peptides have functional properties, as bioactive peptides.

TABLE 4 Various sources of by-products for the production of hydrolysates.

Source	Preparation	Activity	References
Bovine skin gelatin	Serial digestion (*Alcalase, Pronase E, and collagenase*)	Inhibition of lipid peroxidation	Kim et al., 2001
Bovine collagen	Alcalase, collagenase	ACE-inhibition	Zhang et al., 2013
Bovine collagen	Alcalase, papain	ACE-inhibition	Fu et al., 2015
Sheep wool cattle	Proteolytic enzyme	Hydrolys	Mokrejš and Krejčí, 2011
Cow-skin		Acid (4M HCl) hydrolysis	Nouri et al., 2020
Camel skin	Alcalase (A), protease (P), and their combination (AP (1:1))	Hydrolys	Fawale et al., 2023
Horse leg bone	Pancreatin	Enzymatic hydrolysis	Kim et al., 2014
Plasma from Hanwoo cattle	Bacillus protease, papain, thermolysin, elastase, and α-chymotrypsin	Hydrolys	Aung et al., 2023

TABLE 5 The content of the main components in the crude fat of various animals, % (Bockisch, 2015).

Livestock	Moisture	Fat	Protein	Ash
Cattle	9.45–9.96	88.6–88.9	1.16–1.62	0.35
Small cattle	10.5	87.9	1.6	-

Animal fat and adipose tissue processing technologies

According to the type of livestock from which adipose tissue is obtained, raw fat is divided into beef and mutton. Also, each type, taking into account the characteristics of preparation for processing, fatty acid composition and location place in the animal carcass, is divided into two groups.

The first group of raw beef fat consists in: omentum, perirenal, mesenteric, palpable, and subcutaneous fat, obtained by stripping carcasses; adipose tissue from the liver, tail, udder, behind the ear and temporal cavities of the head; fat udder of young animals; fat trim obtained at the cutting meat in sausage, canning and semi-finished industries.

The second group of raw beef fat having following: adipose tissue from the stomach (rumen, books, abomasum); trimmings obtained during manual rite of skins in the shop for slaughtering and butchering carcasses; intestinal fat from manually degreasing the intestines.

Raw fat that obtained from cattle of various types, sex, age, breed, and fatness, differs in the chemical composition. At the higher the animal fatness, the richer it is in fat and the less water it contains. The average data on the chemical composition of raw fat from large and small ruminants above the average fatness are shown in Table 5.

Animal fat processes in various industries. In most cases, about 30–33% of the total fat is used for biodiesel, 25–27% for feed, 22–24% for soap making, 11–13% for pet food, 3–4% for as food, and 1–2% for other purposes. In addition to food and feed preparation, vegetable and animal fats have a potential market for biodiesel production through interesterification (Kumar et al., 2016).

For the facilitating the fat releasing at the heating, the fatty raw materials are pre-crushed on a top. Fat rendering is the process of extracting pure fat from raw fat using the thermal method. In the technology for the production of rendered edible animal fats, there are two methods: wet and dry (Chizoo et al., 2017).

The wet method consists in the fact that during the rendering process, the raw fat is in direct contact with water or live steam. In this case, the protein substances of adipose tissue are hydrolyzed and partially dissolved under the influence of moisture and heat, and fat is released. The temperature during rendering is maintained at the level of 70–90°C with a steam pressure of 1.5–3.0 bar (Baiano, 2014).

The dry method is characterized by the fact that the raw fat is heated through a heating surface. In this case, the moisture contained in the raw material evaporates into the atmosphere during the rendering process or is removed under vacuum. As a result of thermal exposure, the proteins of adipose tissue become brittle, destroyed, and thus fat is released. It turns out a two-phase system: rendered fat and greaves. Depending on the equipment used, the rendering process is carried out at a temperature of 42–120°C and a steam pressure of 0.5–4 bar (Karmakar and Halder, 2019).

After rendering, the fat is subjected to cleaning to remove moisture and suspended impurities from it. The most common methods for cleaning rendered fats are separation and settling. During separation, 10–15% of water at a temperature of 80–90°C is added to the fat. Settling of fat is carried out at a temperature of 90–100°C for 5–6 h. To accelerate settling in order to precipitate protein particles and destroy the emulsion, fat is salted out with dry table salt in an amount of 1–2% by weight of fat (Andersen, 2016).

After cleaning, the fat is cooled in order to obtain a homogeneous structure (pork to 24–35°C, beef—up to 30–35°C) and packaged in a container. Due to the fact that beef fat consists of 54.9% saturated acids, 40.9% unsaturated fatty acids and 4.2% polyunsaturated fatty acids, it is the leader in having saturated fatty acids compared to other types of animal fats (Chizoo et al., 2017).

It is also known that by interesterifying palm oil with beef tallow, the resulting SFC profiles are smoother and the products could potentially serve as base oils for the preparation of specialty fats with a wider range of plasticity. Experiments were also carried out to identify the potential use of this oil in the preparation of bakery products, which showed a positive result (Zhang et al., 2018).

There are also known studies where animal fats that have been processed were used as carbon raw materials for PHAs using collectible strains. Fat residues, bacon rind, udder and waste fat were used as fat raw materials (Favaro et al., 2019).

Thus, animal fat processes in various industries. Mostly, about 30–33% of the total fat is used for biodiesel, 25–27% for feed, 22–24% for soap making, 11–13% for pet food, 3–4% for food production, and 1–2% for other purposes (Kumar et al., 2016).

Conclusion

The meat industry annually generates a huge amount of secondary raw materials and wastes that are not fully processed. Only a small percentage of these products are used to produce high-value-added products such as animal feed, glue, biofuels, fertilizers, etc. Moreover, during of slaughtering livestock, 45% of meat on bones and 55% of by-products and non-food raw materials are obtained. The main reason of the complex processing weakness of the secondary raw materials of animal origin is unavailability of required studies and technologies for each processing stage. The used electrical or hardware slaughter approaches have impact for the quality of meat and offal. The mechanical halal slaughter with blood emission that is often practiced in Kazakhstan and Muslim countries, allows to keep a high nutritional value of the meat products. However, significant possibilities in the agroecology and deep processing have valorization of by-products: carcasses, skins, bones, meat scraps, blood, adipose tissue, horns, feet, hooves, and internal organs. The final processed products could be useful for the food, fodder, medical and technical purposes. For instance, the availability of essential amino and fatty acids, bioactive peptides, collagen derivatives etc. is important for the producing of the functional food products. The considered opportunities for the slaughter wastes and the meat by-products recycling could be applied in many countries, including Kazakhstan. In addition, full recycling of the secondary meat raw materials allows for the increasing of wide-range products with a low prime cost, beneficial and nutritional values. Alternatively, three components of waste hierarchy: Reduce, Reuse, and Recycle would involve a sustainable environment grow in the agroecology.

Author contributions

RA: Conceptualization, Data curation, Investigation, Project administration, Supervision, Writing – original draft, Writing – review & editing. ZA: Conceptualization, Investigation, Software, Writing – original draft. AB: Conceptualization, Data curation, Visualization, Writing – original draft. FT: Conceptualization, Data curation, Supervision, Writing – original draft, Writing – review & editing. KU: Conceptualization, Data curation, Writing – original draft. ZK: Conceptualization, Data curation, Formal analysis, Resources, Visualization, Writing – original draft.

Funding

The author(s) declare that financial support was received for the research, authorship, and/or publication of this article. The study was performed by the financial support of the Science Committee of the Ministry of Science and Higher Education of the Republic of Kazakhstan for the financial support of the research project within the framework of Programme Targeted Funding IRN BR18574252: Complex Waste-Free Processing of Agricultural Raw Materials of Animal and Vegetable Origin.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Abdilova, G., Rebezov, M., Nesterenko, A., Safronov, S., Knysh, I., Ivanova, I., et al. (2021). Characteristics of meat by-products: nutritional and biological value. *Int. J. Mod. Agric.* 10, 3895–3904. Available online at: http://www.modern-journals.com/index.php/ijma/article/view/1264/1058

Abdullah, F. A. A., Borilova, G., and Steinhauserova, I. (2019). Halal criteria versus conventional slaughter technology. *Animals* 9:530. doi: 10.3390/ani9080530

Action Against Hunger (2024). *World Hunger Facts*. Available online at: https://www.actionagainsthunger.org/the-hunger-crisis/world-hunger-facts/ (accessed May 01, 2024).

Ahmad, T., Ismail, A., Ahmad, S. A., Khalil, K. A., Kee, L. T., Awad, E. A., et al. (2020). Extraction, characterization and molecular structure of bovine skin gelatin extracted with plant enzymes bromelain and zingibain. *J. Food Sci. Technol.* 57, 3772–3781. doi: 10.1007/s13197-020-04409-2

Ai, Q., Mai, K., Tan, B., Xu, W., Duan, Q., Ma, H., et al. (2006). Replacement of fish meal by meat and bone meal in diets for large yellow croaker, *Pseudosciaena crocea*. *Aquaculture* 260, 255–263. doi: 10.1016/j.aquaculture.2006.06.043

Alao, B. O., Falowo, A. B., Chulayo, A., and Muchenje, V. (2017). The potential of animal by-products in food systems: production, prospects and challenges. *Sustainability* 9:1089. doi: 10.3390/su9071089

Alibekov, R. S., Kaiypova, A. B., Urazbayeva, K. A., Ortayev, A. E., and Azimov, A. M. (2019). Effect of substitution of sugar by high fructose corn syrup of the confiture on the base of physalis. *Periodico Tche Quimica* 16:697. doi: 10.52571/PTQ.v16.n32.2019.706_Periodico32_pgs_688_697.pdf

Alibekov, R. S., Mustapa Kamal, S. M., Taip, F. S., Sulaiman, A., Azimov, A. M., and Urazbayeva, K. A. (2023). Recovery of phenolic compounds from jackfruit seeds using subcritical water extraction. *Foods* 12:3296. doi: 10.3390/foods12173296

Al-Mahmood, O. A., and Fraser, A. M. (2023). Molecular detection of *Salmonella* spp. and *E. coli* non-O157: H7 in two halal beef slaughterhouses in the United States. *Foods* 12, 347–356. doi: 10.3390/foods12020347

Amicarelli, V., Fiore, M., and Bux, C. (2021). Hidden flows assessment in the agri-food sector: evidence from the Italian beef system. *Br. Food J.* 123, 384–403. doi: 10.1108/BFJ-05-2021-0547

Andersen, A. J. C. (2016). *Refining of Oils and Fats for Edible Purposes*. Amsterdam: Elsevier.

Anjos, O., Fernandes, R., Cardoso, S. M., Delgado, T., Farinha, N., Paula, V., et al. (2019). Bee pollen as a natural antioxidant source to prevent lipid oxidation in black pudding. *Lwt* 111, 869–875. doi: 10.1016/j.lwt.2019.05.105

Aung, S. H., Abeyrathne, E. D. N. S., Ali, M., Ahn, D. U., Choi, Y. S., and Nam, K. C. (2023). Comparison of functional properties of blood plasma collected from black goat and Hanwoo cattle. *Food Sci. Anim. Resour.* 43, 46–60 doi: 10.5851/kosfa.2022.e57

Bah, C. S., Bekhit, A. E. D. A., Carne, A., and McConnell, M. A. (2013). Slaughterhouse blood: an emerging source of bioactive compounds. *Comprehens. Rev. Food Sci. Food Saf.* 12, 314–331 doi: 10.1111/1541-4337.12013

Bah, C. S., Bekhit, A. E. D. A., Carne, A., and McConnell, M. A. (2016). Composition and biological activities of slaughterhouse blood from red deer, sheep, pig and cattle. *J. Sci. Food Agricult.* 96, 79–89 doi: 10.1002/jsfa.7062

Bahru, U. J. (2021). Issues related to animal blood into food products: a review paper. *Food Res.* 5, 12–21. doi: 10.26656/fr.2017.5(3).512

Baiano, A. (2014). Recovery of biomolecules from food wastes—a review. *Molecules* 19, 14821–14842. doi: 10.3390/molecules190914821

Bakhsh, A., Ismail, I., Hwang, Y. H., Lee, J. G., and Joo, S. T. (2018). Comparison of blood loss and meat quality characteristics in Korean black goat subjected to head-only electrical stunning or without stunning. *Kor. J. Food Sci. Anim. Resour.* 38:1286. doi: 10.5851/kosfa.2018.e64

Begum, N., Khan, Q. U., Al-Dalali, S., Lu, D., Yang, F., Li, J., et al. (2024). Process optimization and identification of antioxidant peptides from enzymatic hydrolysate of bovine bone extract, a potential source in cultured meat. *Front. Sustain. Food Syst.* 7:1345833. doi: 10.3389/fsufs.2023.1345833

Bier, J. M., Verbeek, C. J., and Lay, M. C. (2014). Thermal and mechanical properties of bloodmeal-based thermoplastics plasticized with Tri (ethylene glycol). *Macromol. Mater. Eng.* 299, 85–95. doi: 10.1002/mame.201200460

BNSASPR of RK (2019). *Bureau of National Statistics of the Agency for Strategic Planning and Reforms of the Republic of Kazakhstan*. Available online at: https://www.gov.kz/memleket/entities/stat?lang=en (accessed May 5, 2024).

Bobbo, T., Fiore, E., Gianesella, M., Morgante, M., Gallo, L., Ruegg, P. L., et al. (2017). Variation in blood serum proteins and association with somatic cell count in dairy cattle from multi-breed herds. *Animal* 11, 2309–2319. doi: 10.1017/S1751731117001227

Bockisch, M. (2015). *Fats and Oils Handbook (Nahrungsfette und Öle)*. Amsterdam: Elsevier.

Boma, S., Salou, E. W., Agboho, P., Bila, C., Kabore, S., Sabo, A. R., et al. (2022). Reproductive performance of *Glossina palpalis* gambiensis (Diptera:

Glossinidae) when fed frozen or fresh bovine blood meals. *Eur. Sci. J.* 18:138. doi: 10.19044/esj.2022.v18n21p141

Bux, C., and Amicarelli, V. (2022). Separate collection and bio-waste valorization in the Italian poultry sector by material flow analysis. *J. Mater. Cycl. Waste Manag.* 24, 811–823. doi: 10.1007/s10163-022-01366-0

CAN (2023). *CentralAsia.news*. Available online at: https://centralasia.news (accessed May 5, 2024).

Castro-Muñoz, R., García-Depraect, O., León-Becerril, E., Cassano, A., Conidi, C., and Fíla, V. (2021). Recovery of protein-based compounds from meat by-products by membrane-assisted separations: a review. *J. Chem. Technol. Biotechnol.* 96, 3025–3042. doi: 10.1002/jctb.6824

Cetin, E., Temelli, S., and Eyigor, A. (2020). Nontyphoid Salmonella prevalence, serovar distribution and antimicrobial resistance in slaughter sheep. *Food Sci. Anim. Resour.* 40:21. doi: 10.5851/kosfa.2019.e75

Chen, L., Yang, Z., and Liu, H. (2023). Hemoglobin-based oxygen carriers: where are we now in 2023? *Medicina* 59:396. doi: 10.3390/medicina59020396

Chizoo, E., Sunday, U. M., Chimankpam, E. M., Nwoye, O. V., and Uwaoma, O. A. (2017). Extraction of Nigerian beef tallow by wet rendering process and its characterization. *World News Natur. Sci.* 15, 129–138. Available online at: http://www.worldnewsnaturalsciences.com/wp-content/uploads/2012/11/WNOFNS-15-2017-129-138-1.pdf

Cruz-Casas, D. E., Aguilar, C. N., Ascacio-Valdés, J. A., Rodríguez-Herrera, R., Chávez-González, M. L., and Flores-Gallegos, A. C. (2021). Enzymatic hydrolysis and microbial fermentation: the most favorable biotechnological methods for the release of bioactive peptides. *Food Chem.* 3:100047. doi: 10.1016/j.fochms.2021.100047

Da Silva, R. R. (2018). Enzymatic synthesis of protein hydrolysates from animal proteins: exploring microbial peptidases. *Front. Microbiol.* 9:735. doi: 10.3389/fmicb.2018.00735

Day, L., Cakebread, J. A., and Loveday, S. M. (2022). Food proteins from animals and plants: differences in the nutritional and functional properties. *Trends Food Sci. Technol.* 119, 428–442 doi: 10.1016/j.tifs.2021.12.020

Denissova, O., Konurbayeva, Z., Zakimova, A., and Rakhimberdinova, M. (2021). Evaluation of import substitution potential of products from secondary raw materials of animal husbandry. *J. Environ. Manag. Tour.* 12, 341–356. doi: 10.14505//jemt.v12.2(50).04

DHCEU (2024). *Department of Halal Certification EU. Islamic Method of Slaughtering*. Available online at: https://halalcertification.ie/islamic-method-of-slaughtering/"slaughtering/ (accessed May 5, 2024).

Ercen, M. K., Nuriyev, U., and Rethinam, S. (2022). On recycling of animal wastes: a mini-review. *Res. Agricult. Vet. Sci.* 6, 28–36. Available online at: http://jomardpublishing.com/UploadFiles/Files/journals/RV/V6N1/Karatay_et_al.pdf

Favaro, L., Basaglia, M., Rodriguez, J. E. G., Morelli, A., Ibraheem, O., Pizzocchero, V., et al. (2019). Bacterial production of PHAs from lipid-rich by-products. *Appl. Food Biotechnol.* 6, 45–52. doi: 10.22037/afb.v6i1.22246

Fawale, O. S., Mudgil, P., Abdelrahman, R., Baba, W. N., Nirmal, N. P., and Maqsood, S. (2023). Anti-hypercholesteraemic and antioxidative activities of camel skin gelatin hydrolysate: effect of enzyme type, enzyme: substrate ratio and time of hydrolysis. *Int. J. Food Sci. Technol.* 58, 2151–2160 doi: 10.1111/ijfs.16224

Feliu Alsina, N., and Saguer Hom, E. (2023). Microbiological quality and physicochemical characteristics of pork livers supplied by an industrial slaughterhouse. *Pol. J. Food Nutr. Sci.* 73, 130–138. doi: 10.31883/pjfns/162874

Ferronato, G., Corrado, S., De Laurentiis, V., and Sala, S. (2021). The Italian meat production and consumption system assessed combining material flow analysis and life cycle assessment. *J. Clean. Product.* 321:128705. doi: 10.1016/j.jclepro.2021.128705

Fu, Y., Liu, J., Hansen, E. T., Bredie, W. L., and Lametsch, R. (2018). Structural characteristics of low bitter and high umami protein hydrolysates prepared from bovine muscle and porcine plasma. *Food Chem.* 257, 163–171. doi: 10.1016/j.foodchem.2018.02.15

Fu, Y., Young, J. F., Dalsgaard, T. K., and Therkildsen, M. (2015). Separation of angiotensin I-converting enzyme inhibitory peptides from bovine connective tissue and their stability towards temperature, pH and digestive enzymes. *Int. J. Food Sci. Technol.* 50, 1234–1243 doi: 10.1111/ijfs.12771

Fu, Y., Young, J. F., Løkke, M. M., Lametsch, R., Aluko, R. E., and Therkildsen, M. (2016). Revalorisation of bovine collagen as a potential precursor of angiotensin I-converting enzyme (ACE) inhibitory peptides based on *in silico* and *in vitro* protein digestions. *J. Funct. Foods* 24, 196–206. doi: 10.1016/j.jff.2016.03.026

Galanakis, C. M. (2018). *Sustainable Meat Production and Processing*. Cambridge, MA: Academic Press.

Giu, H. M., and Giu, P. D. (2010). *Blood Waste Treatment System for Slaughtered Animals, and Method for Producing High Quality Amino Acid Solution Using Blood Waste. World PatentWO2010KR00586,20100201*. Mississauga, ON: Hanshinn International Corp.

Gizatova, N., Gizatov, A., Zubairova, L., Mironova, I., Nigmatyanov, A., Chernyshenko, Y., et al. (2021). Development of technology for the production of sausage produce using secondary collagen-containing raw materials. *Int. J. Food Stud.* 10:a1. doi: 10.7455/ijfs/10.2.2021.a1

Grasso, S., Brunton, N. P., Lyng, J. G., Lalor, F., and Monahan, F. J. (2014). Healthy processed meat products–regulatory, reformulation and consumer challenges. *Trends Food Sci. Technol.* 39, 4–17. doi: 10.1016/j.tifs.2014.06.006

Helkar, P. B., Sahoo, A. K., and Patil, N. J. (2016). Review: food industry by-products used as a functional food ingredient. *Int. J. Waste Resour.* 6, 1–6 doi: 10.4172/2252-5211.1000248

Hicks, T. M., and Verbeek, C. J. R. (2016). "Meat industry protein by-products: sources and characteristics," in *Protein Byproducts*, ed. G. S. Dhillon (Cambridge, MA: Academic Press), 37–61.

Hopp, M. T., Schmalohr, B. F., Kühl, T., Detzel, M. S., Wißbrock, A., and Imhof, D. (2020). Heme determination and quantification methods and their suitability for practical applications and everyday use. *Analyt. Chem.* 92, 9429–9440. doi: 10.1021/acs.analchem.0c00415

Hsieh, Y. H. P., and Ofori, J. A. (2011). Blood-derived products for human consumption. *Revelat. Sci.* 1, 14–21. doi: 10.31436/revival.v1i01.15

Huygens, D., Saveyn, H., Tonini, D., Eder, P., and Delgado Sancho, L. (2019). *European Commission*. Brussels; Luxembourg: Joint Research Centre.

Imsya, A. (2022). Optimization of the utilization of blood meal with palm oil fronds absorbance fermented as feed stuff to changes of nutrition content. *IOP Conf. Ser.* 1016:e012028 doi: 10.1088/1755-1315/1016/1/012028

Ipharraguerre, I. R., and Clark, J. H. (2005). Varying protein and starch in the diet of dairy cows. II. Effects on performance and nitrogen utilization for milk production. *J. Dairy Sci.* 88, 2556–2570 doi: 10.3168/jds.S0022-0302(05)72932-5

Ismail, I., Hwang, Y. H., and Joo, S. T. (2020). Meat analog as future food: a review. *J. Anim. Sci. Technol.* 62:111. doi: 10.5187/jast.2020.62.2.111

Javourez, U., O'donohue, M., and Hamelin, L. (2021). Waste-to-nutrition: a review of current and emerging conversion pathways. *Biotechnol. Adv.* 53:107857. doi: 10.1016/j.biotechadv.2021.107857

Jayathilakan, K., Sultana, K., Radhakrishna, K., and Bawa, A. S. (2012). Utilization of byproducts and waste materials from meat, poultry and fish processing industries: a review. *J. Food Sci. Technol.* 49, 278–293. doi: 10.1007/s13197-011-0290-7

Jedrejek, D., Levic, J., Wallace, J., and Oleszek, W. (2016). Animal by-products for feed: characteristics, European regulatory framework, and potential impacts on human and animal health and the environment. *J. Anim. Feed Sci.* 25, 189–202 doi: 10.22358/jafs/65548/2016

Karmakar, B., and Halder, G. (2019). Progress and future of biodiesel synthesis: advancements in oil extraction and conversion technologies. *Energy Convers. Manag.* 182, 307–339. doi: 10.1016/j.enconman.2018.12.066

Kim, D., Kim, H. J., Chae, H. S., Park, N. G., Kim, Y. B., and Jang, A. (2014). Anti-oxidation and anti-wrinkling effects of Jeju horse leg bone hydrolysates. *Kor. J. Food Sci. Anim. Resour.* 34:844 doi: 10.5851/kosfa.2014.34.6.844

Kim, H. J., Kim, D., Chae, H. S., Kim, N. Y., and Jang, A. (2017). Nutritional composition in bone extracts from Jeju crossbred horses at different slaughter ages. *Kor. J. Food Sci. Anim. Resour.* 37:486. doi: 10.5851/kosfa.2017.37.4.486

Kim, S. K., Byun, H. G., Park, P. J., and Shahidi, F. (2001). Angiotensin I converting enzyme inhibitory peptides purified from bovine skin gelatin hydrolysate. *J. Agricult. Food Chem.* 49, 2992–2997. doi: 10.1021/jf001119u

Kobzhasarova, Z., Kassymova, M., Orymbetova, G., Nurseitova, Z., and Arapbayeva, D. (2022). Functional meat product. *AIP Conf. Proc.* 2650:e030014. doi: 10.1063/5.0126684

Kohilavani, K., Zzaman, W., Abdullah, W. W. N., and Tajul, A. Y. (2015). Embedding Islamic dietary law into an HACCP approach for application to the poultry slaughtering and processing industry. *Int. Food Res. J.* 22, 2684–2690. Available online at: http://www.ifrj.upm.edu.my/22%20(06)%202015/(59).pdf

Konurbayeva, Z., Denissova, O., Rakhimberdinova, M., and Zakimova, A. (2018). Food security as a formation factor of the import substitution potential of the economy. *J. Appl. Econ. Sci.* 13, 2251–2260. Available online at: https://www.researchgate.net/publication/332251405_Food_security_as_a_formation_factor_of_the_import_substitution_potential_of_the_economy

Kowalski, Z., Kulczycka, J., Makara, A., and Harazin, P. (2021). Quantification of material recovery from meat waste incineration–an approach to an updated food waste hierarchy. *J. Hazard. Mater.* 416:126021. doi: 10.1016/j.jhazmat.2021.126021

Kumar, R., Sundari, I. S., Sen, S., Dasgupta, N., and Chidambaram, R. (2016). Animal fat-and vegetable oil-based platform chemical biorefinery. *Platform Chem. Biorefinery* 5, 361–377. doi: 10.1016/B978-0-12-802980-0.00019-5

Leoci, R. (2014). *Animal by-Products (ABPs): Origins, Uses, and European Regulations*. Latin: Universitas Studiorum.

Limeneh, D. Y., Tesfaye, T., Ayele, M., Husien, N. M., Ferede, E., Haile, A., et al. (2022). A comprehensive review on utilization of slaughterhouse by-product: current status and prospect. *Sustainability* 14:6469. doi: 10.3390/su14116469

Lukin, A. (2018). Possibility of application of collagen preparation in egg white cream manufacturing technology. *Bulgar. J. Agricult. Sci.* 24, 879–884. Available online at: https://www.agrojournal.org/24/05-23.pdf

Lynch, S. A., Mullen, A. M., O'Neill, E. E., and García, C. Á. (2017). Harnessing the potential of blood proteins as functional ingredients: a review of the state of the art in blood processing. *Comprehens. Rev. Food Sci. Food Saf.* 16, 330–344. doi: 10.1111/1541-4337.12254

MA of RK (2022). *Ministry of Agriculture of the Republic of Kazakhstan*. Available online at: https://www.gov.kz/memleket/entities/moa?lang=en (accessed May 7, 2024).

Macrotrends (2024). *Kazakhstan Population 1950–2024*. Available online at: https://www.macrotrends.net/global-metrics/countries/KAZ/kazakhstan/population (accessed May 7, 2024).

Martínez-Alvarez, O., Chamorro, S., and Brenes, A. (2015). Protein hydrolysates from animal processing by-products as a source of bioactive molecules with interest in animal feeding: a review. *Food Res. Int.* 73, 204–212. doi: 10.1016/j.foodres.2015.04.005

Miller, B. A., and Lu, C. D. (2019). Current status of global dairy goat production: an overview. *Asian-Austral. J. Anim. Sci.* 32, 1219–1232 doi: 10.5713/ajas.19.0253

Mokrejš, P., and Krejčí, O. (2011). Producing keratin hydrolysates from sheep wool. *Orient. J. Chem.* 27, 1303–1309. Available online at: https://publikace.k.utb.cz/bitstream/handle/10563/1002760/Fulltext_1002760.pdf?sequence=1&isAllowed=y

Mora, L., and Toldrá, F. (2022). Advanced enzymatic hydrolysis of food proteins for the production of bioactive peptides. *Curr. Opin. Food Sci.* 2022:100973. doi: 10.1016/j.cofs.2022.100973

Navarro, D. M. D. L., Mathai, J. K., Jaworski, N. W., and Stein, H. H. (2018). Amino acid digestibility in six sources of meat and bone meal, blood meal, and soybean meal fed to growing pigs. *Can. J. Anim. Sci.* 98, 860–867. doi: 10.1139/cjas-2017-0217

Nazifa, T. H., Saady, N. M. C., Bazan, C., Zendehboudi, S., Aftab, A., and Albayati, T. M. (2021). Anaerobic digestion of blood from slaughtered livestock: a review. *Energies* 14:5666. doi: 10.3390/en14185666

Nimni, M. E., and Harkness, R. D. (2018). "Molecular structure and functions of collagen," in *Collagen*, ed. K. Budyk (Boca Raton, FL: CRC Press), 1–78.

Nouri, K., Khalaji, S., Zamani, A., and Saki, A. (2020). Acid hydrolysis of gelatin extracted from cow skin: properties and potential for use as a source of small peptides and free amino acids for broiler chickens. *Anim. Product. Sci.* 61, 399–411. doi: 10.1071/AN20411

NSC of KR (2022). *National Statistical Committee of the Kyrgyz Republic*. Available online at: https://stat.kg/en/opendata/category/98/ (accessed May 8, 2024).

Nwogor, U. A., Uche, O. A., Ifeyinwa, E. C., and Emmanuel, A. C. (2015). Effect of locally produced blood meal on growth performance and packed cell volume of broiler chicks. *Am. J. Agricult. For.* 3, 105–108. doi: 10.11648/j.ajaf.20150303.17

Ofori, J., and Hsieh, Y. (2014). Issues related to the use of blood in food and animal feed. *Crit. Rev. Food Sci. Nutr.* 54, 687–697. doi: 10.1080/10408398.2011.605229

Oh, H., Yoon, Y., Yoon, J. W., Oh, S. W., Lee, S., and Lee, H. (2023). Salmonella risk assessment in poultry meat from farm to consumer in Korea. *Foods* 12, 649–668. doi: 10.3390/foods12030649

Pinto, J., Boavida-Dias, R., Matos, H. A., and Azevedo, J. (2022). Analysis of the food loss and waste valorisation of animal by-products from the retail sector. *Sustainability* 14, 2830–2587. doi: 10.3390/su14052830

Potapov, V., Yevlash, V., Parzhanov, Z., Tastanbekova, G., Khamzayeva, S., and Tolegen, M. (2017). Use of food production waste in fodder products. overview of problems and solutions. *Industr. Technol. Eng.* 1, 73–83. Available online at: https://elibrary.ru/download/elibrary_38505335_77444741.pdf

Ragasri, S., and Sabumon, P. C. (2023). A critical review on slaughterhouse waste management and framing sustainable practices in managing slaughterhouse waste in India. *J. Environ. Manag.* 327:116823. doi: 10.1016/j.jenvman.2022.116823

Ravi, H. K., Degrou, A., Costil, J., Trespeuch, C., Chemat, F., and Vian, M. A. (2020). Larvae mediated valorization of industrial, agriculture and food wastes: biorefinery concept through bioconversion, processes, procedures, and products. *Processes* 8:857. doi: 10.3390/pr8070857

Riaz, M. N., Irshad, F., Riaz, N. M., and Regenstein, J. M. (2021). Pros and cons of different stunning methods from a Halal perspective: a review. *Transl. Anim. Sci.* 5:txab154. doi: 10.1093/tas/txab154

Ricke, S., Atungulu, G. G., Rainwater, C., and Park, S. H. (2017). *Food and Feed Safety Systems and Analysis*. Cambridge, MA: Academic Press.

Ritchie, H., Rosado, P., and Roser, M. (2017). *Meat and Dairy Production*. Available online at: https://ourworldindata.org/meat-production (accessed May 8, 2024).

Robinson, S. (2020). *Livestock in Central Asia: from Rural Subsistence to Engine of Growth? IAMO Discussion Paper 193*. Halle: Leibniz Institute of Agricultural Development in Transition Economies (IAMO).

Rohman, A., Nurrulhidayah, A. F., Jamilah, S., Azura, A., and Rashidi, O. (2021). *Issues Related to Animal Blood Into Food Products: a Review Paper*. Malaysia: Food Research (Malaysia).

Roser, M., and Ritchie, H. (2023). *How Has World Population Growth Changed Over Time?* Available online at: https://ourworldindata.org/population-growth-over-time (accessed May 8, 2024).

Ruiz Sella, S. R., Bueno, T., de Oliveira, A. A., Karp, S. G., and Soccol, C. R. (2021). *Bacillus subtilis* natto as a potential probiotic in animal nutrition. *Crit. Rev. Biotechnol.* 41, 355–369. doi: 10.1080/07388551.2020.1858019

SAP of RU (2023). *Statistics Agency Under the President of the Republic of Uzbekistan*. Available online at: https://stat.uz/en/ (accessed May 9, 2024).

Satayev, M., Shakirov, B., Mutaliyeva, B., Satayeva, L., Altynbekov, R., Baiysbay, O., et al. (2012). Mathematical modeling of methoxyanabasine $C_{11}H_{16}N_2O$ polymer solution ultrafiltration. *Heat Mass Transf.* 48, 979–987. doi: 10.1007/s00231-011-0948-8

Schmidt, M. M., Dornelles, R. C. P., Mello, R. O., Kubota, E. H., Mazutti, M. A., Kempka, A. P., et al. (2016). Collagen extraction process. *Int. Food Res. J.* 23:913. Available online at: http://www.ifrj.upm.edu.my/23%20(03)%202016/(1).pdf

Seifdavati, J., Navidshad, B., Seyedsharifi, R., and Sobhani, A. (2008). Effects of a locally produced blood meal on performance, carcass traits and nitrogen retention of broiler chickens. *Pak. J. Biol. Sci.* 11, 1625–1629 doi: 10.3923/pjbs.2008.1625.1629

Sharma, A., Jaiswal, S., Shukla, M., and Lal, J. (2014). Dried blood spots: concepts, present status, and future perspectives in bioanalysis. *Drug Test. Anal.* 6, 399–414. doi: 10.1002/dta.1646

Sharma, S., Imran, Z., Mitra, A., Verma, M., and Joshi, S. (2021). A brief review on the utilization of waste products from the meat industry. *Int. J. Res. Anal. Rev.* 8, 856–863. Available online at: https://www.researchgate.net/profile/Abhirup-Mitra-2/publication/356429891_A_brief_review_on_the_utilization_of_waste_products_from_the_meat_industry/links/619b74d561f0987720c2dbeb/A-brief-review-on-the-utilization-of-waste-products-from-the-meat-industry.pdf

Sherman, V. R., Yang, W., and Meyers, M. A. (2015). The materials science of collagen. *J. Mech. Behav. Biomed. Mater.* 52, 22–50. doi: 10.1016/j.jmbbm.2015.05.023

Shingisov, A. U., Alibekov, R. S., Myrkalykov, B. S., Musayeva, S. A., Urazbayeva, K. A., and Iskakova, S. K. (2016). Physicochemical characteristics of the new polyphyto-component composition for food industry. *Biosci. Biotechnol. Res. Asia* 13, 879–886. doi: 10.13005/bbra/2110

Shirsath, A. P., and Henchion, M. M. (2021). Bovine and ovine meat co-products valorisation opportunities: a systematic literature review. *Trends Food Sci. Technol.* 118, 57–70 doi: 10.1016/j.tifs.2021.08.015

Shurson, G. C. (2020). "What a waste"—can we improve sustainability of food animal production systems by recycling food waste streams into animal feed in an era of health, climate, and economic crises? *Sustainability* 12:7071. doi: 10.3390/su12177071

Sinclair, M., Hötzel, M. J., Lee, N. Y., De Luna, M. C. T., Sharma, A., Idris, M., et al. (2023). Animal welfare at slaughter: perceptions and knowledge across cultures. *Front. Anim. Sci.* 4:1141789. doi: 10.3389/fanim.2023.1141789

Skokov, R., and Dyussegalieva, B. (2023). Current state of livestock economy in Kazakhstan. *E3S Web Conf.* 462:e01023. doi: 10.1051/e3sconf/202346201023

Stepień, A., and Rejmer, W. (2022). Effect of fertilization with meat and bone meal on the production of biofuel obtained from corn grain. *Energies* 16:21. doi: 10.3390/en16010021

Swe, K. H., Lay, K. K., Aung, Y. L., Aung, Y., Thiri, T., Oo, H. L., et al. (2022). Effect of animal by-products on the growth performance of broiler chickens. *J. Livestock Sci.* 13:66. doi: 10.33259/JLivestSci.2022.58-66

Tastemirova, U., Mukhtarkhanova, R., Alimardanova, M., Alibekov, R., and Shingisov, A. (2022). Impact of vacuum freeze-drying on the reconstituted camel milk composition. *Food Sci. Technol.* 42:61722. doi: 10.1590/fst.61722

Teshnizi, Z. M., Robatjazi, S. M., and Mosaabadi, J. M. (2020). Optimization of the enzymatic hydrolysis of poultry slaughterhouse wastes using alcalase enzyme for the preparation of protein hydrolysates. *Appl. Food Biotechnol.* 7, 153–160. doi: 10.22037/afb.v7i3.28417

Thi, H. V., Nguyen, M. L., Tran, L. T., Ngo, A. D., Nguyen, K. H., Thi, T. M. N., et al. (2023). Food poisoning: a case study in Vietnam. *Case Stud. Chem. Environ. Eng.* 7:100295. doi: 10.1016/j.cscee.2022.100295

Toldrá, F., Basu, L., and Ockerman, H. W. (2023). "Sustainability. I: edible by-products," in *Lawrie's Meat Science* (Sawston: Woodhead Publishing), 707–726.

USDA Report (2022). *Kazakhstan Finalizes 2021–2030 Agricultural Development Policy Document. USDA, Foreign Agricultural Service. Report Number: KZ2022-0010. 52.* Available online at: https://apps.fas.usda.gov

UZGEN TMPP (2023). *UZGEN Technological Meat Processing Plant*. Available online at: https://www.gentes.com.tr (accessed May 10, 2024).

Woodgate, S. L., Wan, A. H., Hartnett, F., Wilkinson, R. G., and Davies, S. J. (2022). The utilisation of European processed animal proteins as safe, sustainable and circular ingredients for global aquafeeds. *Rev. Aquacult.* 14, 1572–1596. doi: 10.1111/raq.12663

WPR (2024). *Sheep Population by Country 2024*. World Population Review. Available online at: https://worldpopulationreview.com/country-rankings/sheep-population-by-country (accessed May 10, 2024).

Zakharova, L. M. (2014). Development and introduction of new dairy technologies. *Foods Raw Mater.* 2, 68–74. doi: 10.12737/5462

Zhang, H., Liu, H., Qi, L., Xv, X., Li, X., Guo, Y., et al. (2023). Application of steam explosion treatment on the collagen peptides extraction from cattle bone. *Innov. Food Sci. Emerg. Technol*. 85:103336. doi: 10.1016/j.ifset.2023.103336

Zhang, Y., Olsen, K., Grossi, A., and Otte, J. (2013). Effect of pretreatment on enzymatic hydrolysis of bovine collagen and formation of ACE-inhibitory peptides. *Food Chem*. 141, 2343–2354. doi: 10.1016/j.foodchem.2013.05.058

Zhang, Z., Shim, Y. Y., Ma, X., Huang, H., and Wang, Y. (2018). Solid fat content and bakery characteristics of interesterified beef tallow-palm mid fraction-based margarines. *RSC Adv*. 8, 12390–12399. doi: 10.1039/C8RA00769A

Zheleuova, Z. S., Uzakov, Y. M., Shingisov, A. U., Alibekov, R. S., and Khamitova, B. M. (2021). Development of halal cooked smoked beef and turkey sausage using a combined plant extracts. *J. Food Process. Preserv*. 45:e15028. doi: 10.1111/jfpp.15028