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MANAGEMENT OF WASTE AND BY–PRODUCTS FROM MEAT INDUSTRY

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Abstract: Meat industry is a major generator of organic waste in the food processing sector. On the technological flows of slaughterhouses, solid and liquid waste is generated, represented by certain parts of slaughtered animals, considered worthless for the operator of the slaughterhouse. Also, large amounts of wastewater are generated as a result of washing animal carcasses, processing organs, cleaning equipment and halls etc. European regulations for waste management seek to minimize the amount of waste that ends up in ecological landfills and emphasize the importance of recycling and recovery of resources. In this context, this paper reviews some of the most well–known methods and technologies for the treatment and recovery of waste and by–products resulting from technological flows from meat industry.
Keywords: slaughterhouse waste, blood, protein, wastewater, circular economy, waste recovery

INTRODUCTION

Animal slaughterhouses and meat processing factories are key areas of the food industry, which is constantly evolving in response to the requirement to feed a rising population with various needs.

Global production of pork, beef and poultry has doubled in the last decade and is expected to increase steadily until 2050 (Bustillo–Lecompte and Mehrvar, 2017). In 2022, global meat production was estimated at about 360 million tons (in carcass weight equivalent) (FAO, 2022), and is projected to expand by nearly 44 Mt by 2030 (OECD–FAO, 2021) (Figure 1).

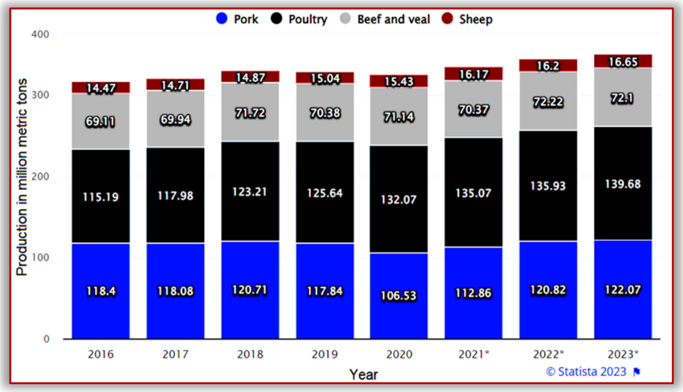

Figure 1 – Global production of meat from 2016 to 2023, by type (www.statista.com)

Global consumption of meat proteins is expected to increase by 14% by 2030 compared to the base period average of 2018–2020, owing primarily to income and population growth. By 2030, protein availability from beef, pig, poultry, and sheep meat is expected to increase by 5.9%, 13.1%, 17.8%, and 15.7% respectively (OECD–FAO, 2021).

GENERATION OF WASTE AND BY–PRODUCTS ON TECHNOLOGICAL FLOW IN SLAUGHTERHOUSES

Slaughterhouses produce not just meat and products for human consumption, but also solid waste and other by–products, as well as large amounts of wastewater (Cuetos et al., 2008). The majority of meat industry waste and by–products are generated during the slaughter of animals for human consumption, but also during the disposal of deceased animals and disease control efforts.

Regardless of the species of animal, the slaughterhouse is the site where the early phases of meat processing take place. These include operations like stunning, killing, bleeding, removing hide or fur, evisceration, offal removal, carcass cleaning, trimming, and carcass dressing. Secondary processes like cutting, deboning, grinding, and processing into consumer products may also take place on the same site.

Figure 2 depicts the flow of operations in the slaughtering process, with the waste and by–products resulting from each operation.

More than 330 million animals slaughtered annually in the European Union generate more than 18 million tons of waste and meat by–products (Izydorczyk et al., 2022), including blood, bones, fat, trimmings, skin, hair, organs, viscera, horns, hooves, skulls, urine, intestinal contents etc, during the slaughtering and processing of meat and stomach, which must be treated and disposed of ecologically, in order to protect the environment and human health. Countries have varied policies regarding the usage of blood, stomach contents, and meat and bone meal.

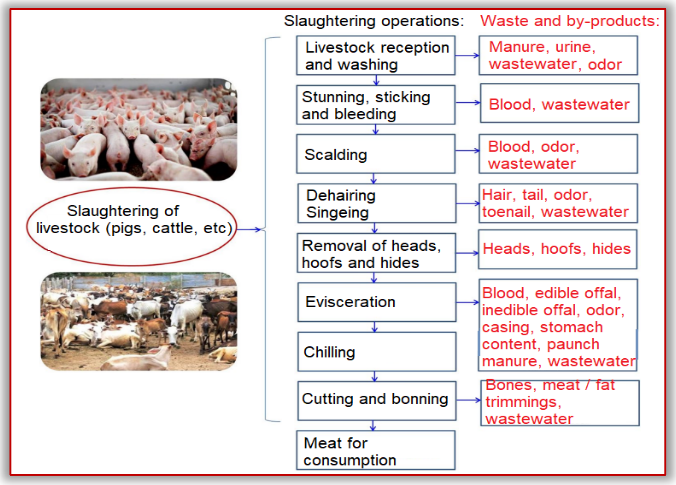

Figure 2 – Slaughtering process flow and resulting waste / by–products (Mozhiaras and Natarajan, 2022)

BY–PRODUCTS FROM MEAT INDUSTRY

Animal by–products include animal heads (with their parts), internal organs, legs, hooves, horns, tails, bones, blood, endocrine glands, fats, intestines, stomach, etc. The heads, intended for use as such, are cleaned, split open, the lips, eyes and skull are removed, and the brain and glands are harvested. Beef, sheep and pork tongues intended for processing in the form of sausages and preserves are subjected to mechanized cleaning. Brains, livers, hearts, lungs, kidneys, spleens and udders from healthy adult cattle, after processing, are delivered fresh or chilled. Offal products include cattle bellies and legs, pig's feet, ears and tails.

Animal by–products that are not intended for human consumption constitute a potential source of risks for public and animal health. Eliminating all animal by–products is not a realistic option, as it would lead to unsustainable costs and risks to the environment. A wide range of animal by–products is currently used in important production sectors: the pharmaceutical industry, the feed industry and the leather industry. New technologies have widened the possibilities of using animal by–products or derived products in many production sectors, especially for the purpose of energy production.

WASTE FROM MEAT INDUSTRY

Slaughterhouse waste consists of the inedible remains of a slaughtered animal that cannot be sold or used in meat products. From the group of waste, which are inedible remains, we can mention: corneous material, hair, teeth, bones, cleaning from animal skins, remains from intestines and bellies, stomach contents, bacon fringes, tallow, raw and confiscated waste (waste: eyes, trachea; confiscated: cans, whole animals, organs, meat preparations), inedible organs, raw blood for feed use, technical fat obtained by melting waste and confiscated fats, from decanting the waters in which the fatty products were boiled etc.

Meat waste mostly consists of organic components, water, and phosphorus compounds (Rahimpour Golroudbary et al., 2019). Solid, liquid, and gaseous wastes from slaughterhouses and meat processing industries have the potential to contaminate the environment and endanger the human health (Matheyarasu et al., 2016). The meat sector contributes significantly to global greenhouse gas emissions, producing methane, nitrous oxide, and carbon dioxide at various phases of meat processing.

These emissions can occur directly as a result of energy consumption or indirectly as a result of raw material production, livestock herding and movement, animal transport and slaughter, meat cleaning and packaging, waste, and wastewater. During the 2018–2020 base period, greenhouse gas emissions from meat production accounted for approximately 54% of overall agricultural emissions (in CO_2 eq.).

The 5% rise in emissions from the meat sector by 2030 is significantly smaller than the increase in meat production, owing mostly to increased poultry production and expected higher meat yield from a given stock of animals. The adoption of innovative methods to reduce CH_4 emissions could lower future per unit emissions even further (OECD–FAO, 2021).

Based on the risk they provide to human and animal health, there are three categories of animal waste established by the European Commission in 2009 (EC Regulation 142/2011):

— Category 1 = exceptional risk or extremely high risk waste – reffers to waste from animals infected with transmissible spongiform encephalopathy (TSE) or animals slaughtered for TSE eradication, as well as specified risk materials. Waste in this category must be incinerated or co–incinerated, or it can be utilized to produce biodiesel.
— Category 2 = high / medium risk waste – reffers to residues of some compounds beyond the authorized limits, as well as foreign materials, dead animals, manure, and the contents of killed animals' digestive tracts. This type of waste is converted into gasoline, biodiesel, biogas, or fertilizer.

— Category 3 = low–risk waste – reffers to products such as carcasses and parts of slaughtered animals that are suitable for human consumption, but are not ultimately intended for human consumption for commercial reasons, or are rejected as unfit for human consumption, even if they do not show signs of disease transmissible to humans or animals. These wastes include ruminant and non–ruminant bones, hides, skins, horns, feet, and blood.

Slaughterhouse waste possesses all of the necessary qualities to be classified as hazardous waste requiring specific care. The amount of waste produced is determined on the type of animal slaughtered and its level of fattening. The total quantity of waste produced per slaughtered animal is around 35% of its weight. It is estimated that 50–54% of a cow, 52% of a sheep or goat, 60–62% of a pig, 68–72% of a chicken, and 78% of a turkey are used for meat, with the remainder discarded as waste (Kekere et al., 2020).

METHODS TO MANAGE WASTE AND BY–PRODUCTS FROM THE MEAT INDUSTRY

Some of the most important causes of inadequate slaughterhouse waste management in low–income countries are a lack of properly constructed slaughterhouses, as well as a lack of legislation to restrict and prohibit indiscriminate dumping of hazardous waste, insufficient capacity of waste handlers, and inefficient equipment (Singh et al., 2018).

There is a dearth of well–organized policies in developing nations for the disposal of solid and liquid waste generated in slaughterhouses, waste that is typically disposed of without treatment or processed through composting.

International regulations for the treatment and handling of meat by–products are very strict to avoid transmissible forms of spongiform encephalopathy.

The rules for managing each category of waste are specified in the European Commission Regulation no. 1069/2009 of the European Parliament and the Council of 21 October 2009.

The European Commission's Regulation No. 142/2011, revised in 2022, stipulates the sanitary criteria for the storage, transportation, and labeling of animal by–products and derived products that are not intended for human use. Before storage or transportation, these byproducts must be transformed into safe materials (EC Regulation 142/2011).

Reduce, reuse, and recycle principles, cleaner production, resource efficiency, and a zero waste strategy are all part of the European Union waste hierarchy. The zero–waste concept is a set of waste prevention recommendations that promotes restructuring resource lifecycles to ensure that every output of manufacturing is reused (Nenciu et al., 2022).

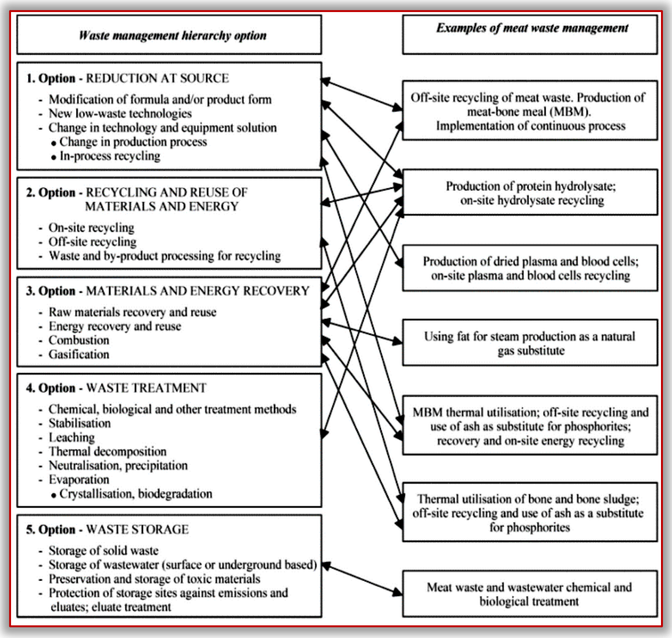

Figure 3 – Hierarchy of pollution prevention options and examples of meat waste management (Kowalski et al., 2021)

The concept of valorizing waste streams to get high–value goods coincides with the concept of sustainable development, which strives to ensure food security, environmental protection, and energy efficiency. Such concepts are supported by emerging global economies.

According to the principles of waste hierarchy and circular economy, a general model that can be applied for waste management in meat industry was proposed by Kowalski et al. (2021).

DISPOSAL OF ANIMAL WASTE AND MORTALITY LOSSES

- **Non–compliant disposal of waste from the meat industry.** In many non–compliant slaughterhouses, the stomach contents of slaughtered animals and other solid waste is still disposed of in open fields, and the liquid phase from the washing hall (sewage containing blood) is allowed to drain into drains.

Incorrect management of various waste streams from animal slaughter can degrade soil, water and air quality due to high loading of nitrogen and phosphorus, odorous compounds, heavy metals, antibiotics and pathogenic microorganisms (Salmonella spp., enterococci, staphylococci, lactobacilli, phytoestrogens and antibiotic resistance genes) (Kefalew and Lami, 2021).

- **Landfilling.** The final disposal of waste in landfills is the least desirable management option, as it leads to several environmental problems, including leaching, emissions of greenhouse gases (methane) and the production of unpleasant odors.

Moreover, landfilling has increasing costs imposed by European Union landfill directives, which will ultimately limit the application of landfilling as a waste management method.

- **Disposal of mortality losses.** Dead animals in livestock farms due to natural causes or due to diseases or epidemics, as well as dead animals in waiting areas in slaughterhouses (in the animal receiving and holding area), represent the so–called mortality losses.

In the case of the occurrence of epizootics, it is necessary to locate the source of infection and immediately remove the sick animals/dead bodies. Often, to avoid the spread of disease outbreaks and pathogens, mortality losses are buried in ecological landfills, but many landfills no longer accept dead animals, which leaves the farmers with the option of on–farm burying of dead animals. In this case, the current regulations provide for the sealing of burrial pits and the use of biochar for soil and groundwater remediation.

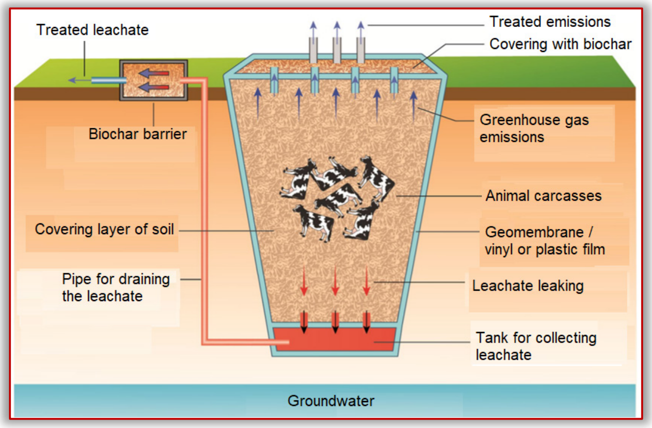

Figure 4 – Burying of mortality losses in compliance with environmental protection norms (Ungureanu N., 2022)

Another option is to incinerate the mortality losses in incinerators authorized for this type of waste. Incineration of animals with swine fever, bird flu is the only solution that ensures the complete neutralization of the pathogens.

BIOLOGICAL TREATMENT OF WASTE FROM MEAT INDUSTRY

- **Composting.** Composting is an ecological management strategy and the primary biological process utilized in many countries to stabilize organic wastes and minimize the amount and volume of solid organic waste (Nenciu et al., 2022a).

Composting involves the transformation of organic compounds into carbon dioxide, ammonia–nitrogen or complex recalcitrant materials (also known as humic substances) under aerobic conditions. The composting process requires moisture and mechanical energy to mix and aerate the waste. Meat waste is high in nutrients and minerals, so it is suitable for composting. Mortality losses owing to epidemics are frequently composted, especially when there is a risk of rapid spread. Composting of mortality losses is characterized by the microbial degradation of a centralized source of nitrogen (the carcass) surrounded by carbonaceous material.

Carbon gives energy to decaying microbes, whereas tissues and carcass fluids provide nitrogen for microbial protein synthesis. Composting of animal carcasses inactivates pathogens, controls odors, and reduces exposure to flies or other insects in a safe, biosecure, and environmentally sustainable manner. During a disease outbreak, it is preferable for composting to take place indoors, and not on outdoor platforms, to minimize the biosecurity risks.

Figure 9 – Composting piles of mortality losses, outdoors and indoors (Ungureanu N., 2022)

Compost is a natural fertilizer and has many applications, including mushroom growing, mulching, improving soil structure in orchards, and making compost tea (Nenciu et al., 2022b). Compost obtained from solid waste from the meat production chain has high electrical conductivity due to the high concentration of salts. Excess salts are a limiting and phytotoxic factor for the development of the seedling root system and can cause delays in seed germination.

- **Anaerobic digestion.** Many countries have adopted anaerobic digestion as the main method for treating a wide range of organic wastes, including livestock waste and slaughterhouse waste. Financial benefits, social benefits for climate, health, jobs, but also poverty reduction benefits are included in the economic benefits of biogas technology.

Biogas is a gaseous mixture consisting of methane (max. 80%) and carbon dioxide (min. 20%), along with small amounts of hydrogen, hydrogen sulfide, water vapor, traces of ammonia and nitrogen. With the help of cogeneration plants, biogas can be transformed into thermal and electrical energy. In addition to biogas, anaerobic digestion also produces digestate (an organic fertilizer) with excellent nutritional characteristics, with sufficient levels of phosphorus, potassium, calcium, magnesium, manganese, iron and zinc.

Figure 10 – Tubular biodigesters for slaughterhouse wastewater (www.wisions.net)

Figure 11 – Biogas station serving a livestock farm (Ungureanu N., 2022)

Slaughterhouse waste (especially stomach and intestinal contents and blood) is a good substrate for biogas production because it contains a high concentration of organic substances (proteins and lipids) that have a high potential to produce large amounts of methane at different volatile solid concentrations (Kefalew and Lami, 2021). The chemical properties of slaughterhouse wastes are comparable to those of municipal sewage, however the former is highly concentrated wastewater with 45% soluble and 55% suspended organic content (Zafar S., 2023). Because of the long–chain fatty acids that inhibit methanogenic processes, the hydraulic retention time of these wastes in the digester is prolonged, around 50 days.

Anaerobic digestion also aids in the reduction of high BOD_5 levels in slaughterhouse wastewater; these wastewaters typically have high organic resistance, which might impair the anaerobic process's efficacy. As a result, an anaerobic wastewater treatment system is frequently followed by further treatment to remove total phosphorus, total nitrogen, and harmful microbes.

THERMOCHEMICAL TREATMENT OF WASTE FROM MEAT INDUSTRY

Waste and by–products from the meat industry can be treated by thermal processes – burning (incineration), pyrolysis and gasification. Among these processes, incineration is considered to be the most effective. The advantage of thermal waste treatment processes is the possibility of recovering the heat from the combustion gases and the possibility of valorizing the residual ash.

- **Incineration.** Incineration is an established technology that has been used to reduce waste volumes while also producing electrical energy and heat. Incineration takes place at high temperatures (850–1100 °C), that ensure the rapid disposal of carcasses (birds, pigs, sheep, cattle, equids, pets), derived products, confiscated or expired, resulting from activities such as animal husbandry, slaughter or meat processing.

To increase the biosecurity in animal farms, slaughterhouses or meat preparation factories, it is mandatory to eliminate waste of animal origin as soon as possible after its generation or to store it in good conditions until incineration. Some drawbacks of incinerating meat waste are its high moisture content, difficult ignition, respectively unsteady, unstable, and incomplete combustion (Hamawand et al., 2017). Waste incineration can endanger the environment and human health owing to carbon dioxide, nitrogen, and sulfur emissions, dioxins, and other toxins. Noxious odors can be offensive to the local community (Girotto et al., 2015). Incinerators shouls be equipped with high efficiency retention systems for pullutants and with combustion heat recovery systems. The residual ash produced by the incineration of animal by–products is an ideal product for the manufacturing of ecophosphate (monocalcium phosphate), a low–carbon phosphorus fertilizer (Bujak J.W., 2015). Ecophosphate is a mineral fertilizer present in proteins, phytin, and organic nucleic acids that is crucial in plant nutrition. Phosphorus–containing fertilizers have a significant impact on the quality of farmed plants.

- **Pyrolysis.** Pyrolysis is the thermal breakdown of waste, typically at 400–800°C, in the absence of oxygen, that produces a solid residue (biochar), liquid (bio–oil), and gas (Cascarosa et al., 2013). Biochar is a coal that can be used as a solid fuel or as a soil conditioner. Bio–oil has the highest energy content compared to biochar and pyrolysis gas.

Therefore, it has high potential to be used as a liquid fuel in energy applications (Hassen–Trabelsi et al., 2014). Pyrolysis bio–oil can also be used as a source of chemicals depending on its characteristics such as water fraction, viscosity, density, chemical composition and pH. Fast pyrolysis is one of the emerging technologies, it takes place in the absence of air and produces solid, liquid and gaseous fuels. The main advantage of this technology is the provision of energy from waste resources at milder operating conditions, typically around 250–500°C, compared to 800–900°C for gasification and the short treatment time for anaerobic digestion.

MATERIAL RECOVERY (VALORIZATION)

The large volumes of waste generated in the meat industry must be treated through technologies that allow the recovery of materials. Recovery is especially carried out for some edible parts of slaughtered animals, parts known generically as by–products, which have the potential to be used for human consumption, either directly or through further processing.

By–products such as carcasses of slaughtered animals, hearts, livers, kidneys, have high contents of vitamins, essential amino acids, minerals and trace elements; therefore, they are traditionally consumed as food or as nutritious food ingredients, or as sources of valuable compounds (Toldra et al., 2021).

- **Valorization of fats.** In the food industry, edible fats separated during meat processing can be used in as adjuvants in baking, frying agents flavor enhancers, meat extracts that are used for stock and soups; gelatin obtained from collagen has multiple applications in a wide variety of foods (Toldra et al., 2021); lard and beef tallow are used for cooking and frying.

In the cosmetics, pharmaceutical and chemical industries, fats are used in hand and body lotions, creams and bath products. Melted fats can be used to polymerize rubber and plastic. In bioenergy, biodiesel can be obtained from animal fats. The technology consists of transesterifying the fats with a short–chain alcohol and a catalyst (usually KOH and NaOH), to produce a mixture of fatty acid methyl esters that make up biodiesel and glycerol. Glycerol is a by–product that can be recovered. Animal fats contain free fatty acids and water which affect the transesterification reaction and reduce the yield of biodiesel because soap can form. Pretreatment is needed to remove excess water by drying or with silica gel, remove free fatty acids by neutralization and separation, and remove suspended solids by filtration.

- **Valorization of bones.** Bones, a significant by–product in terms of volume, account for 16–20% of the total body volume of animals exposed to industrial slaughter, ranking second in terms of physical composition only to muscle tissue (47–58%), which is a raw material consumable. To a lesser extent, bones are processed and used directly as food products (when accompanied by edible stuff).

In some countries, including Romania, a significant part of the by–products represented by pork, chicken or fish bones become raw materials for the industrial production of collagen and gelatin, important products intended for human consumption. If there is neither flesh or fat in the bones of slaughtered animals, they are often used for technological purposes (Zaharioiu et al., 2022):

- the manufacture of bone meal (for animal husbandry, food industry or vegetable cultivation);
- obtaining collagen, gelatin, concentrates intended for pets;
- the manufacture of bone glues;
- the production of compost from bones and skins (in the USA) etc.

Bone meal is obtained by grinding calcined bones and is a very valuable material, providing energy, vitamins, proteins, minerals, in variable proportions, with a high degree of digestibility.

Bone meal is currently prohibited for use as animal feed under the European directives (Regulation (EC) No. 999/2001). Starting with 1.08.2005, in Romania and in several EU countries, the administration of processed proteins in the feed of farm animals was prohibited. The ban was imposed by the confirmation of the spread of bovine encephalopathies, due to the use in animal feed of flour derived from the processing of slaughterhouse by–products. At present, the specialized commissions within the European Union are debating the readmission of protein flours in the feeding of animal species that do not risk the transmission of prion encephalopathies.

Bone meal is used in agriculture as a root development stimulant applied at the start or conclusion of the plant development cycle, and to raise soil phosphorus levels, with most forms of bone meal having a nitrogen–phosphorus–potassium (NPK) concentration of 3–15–0. However, before applying bone meal on the soil, a preliminary soil test is essential, as it is known that the fertilizer's efficiency declines as the pH value rises above 7.0.

Bones for obtaining collagen must come exclusively from animals cut in the slaughterhouse, whose carcasses have been proven suitable for human consumption, following ante–mortem and post–mortem inspection. Only raw material from registered and authorized companies is allowed.

Gelatin is obtained by thermal denaturation of collagen from bones, the final product being a colloidal protein substance, used in the pharmaceutical and food industry, in bacteriology and technical operations. The gelatin production process must be ensured by a bone raw material from ruminants born, raised and slaughtered in regions/countries classified with a low incidence of bovine spongiform encephalopathy, in accordance with the specific community legislation, transposed into the national legislation.

- **Valorization of keratin waste (horns, hooves, hair).** Horns heated to 110–120°C become plastic, so they can be used to make buttons, piping and other haberdashery. Horn flour can be used for industrial purposes – in the machine building industry, in the metallurgical industry for cementing steel or in the industry for the manufacture of plastic masses called galalite.

For the purpose of complex utilization, amino acids can be obtained through acid hydrolysis of the horns – glutamic acid, tyrosine, cystine, arginine, histidine, lysine, leucine, valine, phenylamine, complex amines. By adding them to feed, the biological value of protein feed can be increased (Crăciun et al., 2004). Keratinous raw materials can also be used as organo–mineral fertilizers, as they contain phosphorus, calcium and nitrogen. Animal hair is an important raw material for obtaining brushes, brushes, filling materials in upholstery. The hair on the ears and forehead of the animals is finer and is used to make fine picture brushes, and the hair on the tail is used as a filling material.

- **Valorization of animal skin.** The skin is a relevant by–product, representing 7–8% of the animal's weight. From an economic point of view, animal skin is a key material, generating well–being and jobs in a variety of value chains, in areas such as: footwear, clothing, leather goods, furniture, car upholstery, aircraft, or many other products for domestic use.

The raw materials of European tanneries are raw hides of which over 99% come from animals raised primarily for wool, milk and/or food production. This fact clearly illustrates the ecological role of tanneries: the valorization of a secondary product that, in the absence of the leather industry, would have been finally disposed of in the ecological landfill.

The analysis of social and environmental indicators demonstrated that tanneries in Europe are increasingly involved in the ethical and social aspects of this type of business and that, through continuous investment, substantial improvements in process efficiency and pollution prevention and control can be ensured.

- **Pharmaceutical and enzymatic preparations obtained from slaughterhouse by–products.**

Endocrine glands and some organs such as pituitary gland, pineal gland, thymus, thyroid, parathyroid, adrenal glands, pancreas, testicles, ovaries, liver of cattle, pigs and sheep, spleen of cattle, bile of cattle, eyes of cattle are harvested to be processed as chemical–pharmaceutical by–products. Liver extracts are used to combat anemia. Splenin and other extracts used in the fight against leukemia are obtained from the spleen. A hypotensive substance is extracted from the kidneys of cattle and pigs. Lecithin, cholesterol, cephalin, thromboplastin, some enzymes are extracted from the brain and marrow of cattle, and therapeutic substances used to treat nervous disorders and to prevent hemorrhages are also obtained (Crăciun et al., 2004). Powdered pepsin is obtained from the pig stomach mucosa (red mucosa), used to coagulate milk (pepsin L) and to digest samples used to detect trichinosis in pork meat (pepsin T) (Ungureanu N., 2022). From the stomach of young animals during the period in which they feed on milk, curd (chymosin) is extracted, which has the property of coagulating milk by precipitating casein in the form of calcium caseinate, being used in the manufacture of cheeses (Crăciun et al., 2004).

- **Other directions for the recovery of by–products and waste from slaughterhouses and meat processing plants include:**
- Petfood production. The main way to recover solid waste from the meat industry, which has a high protein and nitrogen content, is to use it in the production of animal feed (fish feed and pet food).
- Aquaculture fish species feed on high–protein and energy–rich feed, and meat by–product meal could be a very suitable option to support the aquaculture sector that relies heavily on high–quality fishmeal, but also for to maintain a sustainable environment.
- Growth of insect larvae. A more recent method of recycling slaughterhouse waste is to turn it into food for the growth of insect larvae intended for human consumption or the biofertilizer industry for agricultural crops. Sludge from slaughterhouse wastewater treatment is rich in nutrients and could be a feasible substrate for large–scale insect larval growth; larvae can be used as alternative food and their residues can be used as biofertilizer.
- **Valorization of blood.** The first by–product obtained from animal slaughter is blood, a mixture of plasma (up to 60%) and blood cells (30–40%), and also a highly perishable product that must be processed as soon as possible after slaughter.

Blood is one of the most important pollutants dissolved in slaughterhouse wastewater and is also the most problematic component due to its ability to inhibit floc formation. Typically, cattle contain up to 22.72 kg of blood/animal, of which only 15.9 kg of blood is recovered from the animals' bleeding area.

The remaining 6.8 kg of blood is lost in the wastewater stream, with a biochemical oxygen consumption (BOD_5) of 2.25–3 kg /1000 kg slaughtered animals (Amenu D., 2014) and chemical oxygen consumption (CCO) of 0,375 kg/L (Masse și Masse, 2000). At the slaughter operation, 4–6 L of blood/animal are obtained in pigs and 20–35 L of blood/animal in adult cattle; when blood is collected for recovery, there is a loss of approximately 0.5 L in slaughtered pigs and 2 L in slaughtered adult cattle. Even with proper handling during meat processing, blood losses in the wastewater stream reach 2 L of blood / beef and 0.5 L of blood / pig (de Sena et al., 2009).

The blood of healthy, unmedicated animals is sterile and contains 17–19% protein of high nutritional value. Due to its chemical and biological composition, the blood resulting from the slaughter of animals is an extremely important raw material both for the food industry and for obtaining blood preparations in the pharmaceutical industry. If it is hygienically collected in sanitary abattoirs, the blood can be turned into blood meal – a protein concentrate. In the food industry, stabilized whole blood can be used as an additive in some meat preparations, or blood pigments can be used to color meat preparations. However, cow and sheep blood is rarely used for human consumption.

Blood meal is obtained by drying the blood of cattle and pigs. Drying methods include: solar drying, oven drying, drum drying, flash drying, spray drying. Blood meal is a dry powder (it has a moisture content of less than 10–12%), hydroscopic, inert, which must be stored in a dry place so as not to spoil. Like other animal products, its sale and use is regulated in some countries for certain species for safety reasons. Blood meal has long been used as animal feed because it is rich in protein (it has a crude protein content of 84%) and can supplement diets based on cereals, vegetable by–products and forages.

It has proven to be a satisfactory substitute for other protein sources in various animal production diets for dairy cattle, beef cattle, sheep, pigs, poultry, various fish species and silkworms (Ungureanu N., 2022). For safety reasons, blood must be heated before being used in animal feed: a minimum temperature of 100 °C for 15 minutes is required to eliminate potential infections (salmonella, mycotoxins, prions). The use of blood meal in animal feed has been restricted in the European Union since 2000 (by Council Decision 2000/766/EC), while blood products from non–ruminant animals have been approved for use in aquaculture since 2006 (Mulik J., 2014).

Blood meal can also be used as an organic fertilizer with a high nitrogen content. With a composition of N = 13.25%, P = 1% and K = 0.6%, blood meal is one of the largest non–synthetic sources of nitrogen (Ungureanu N., 2022). Blood can also be used for medicinal purposes. Blood can make fibrin (a fibrous protein involved in blood clotting); serum can be separated from whole blood to obtain therapeutic serum; or amino acids and peptides can be produced. The following technical products can be obtained from blood: technical albumin treated with formalin, used in the preparation of hides before polishing, or in the textile industry as an agglutinate so that the dyes do not spread on the unprinted portions of the fabrics and as a finishing substance. Technical albumin is also used as an additive to obtain plastic masses; blood glue, which is obtained from blood meal, water and quicklime.

WASTEWATER IN MEAT INDUSTRY

Water is utilized in the meat industry for a variety of functions, including as an ingredient, a source of initial and intermediate cleaning, an efficient means of transporting raw materials, and the primary agent used for sterilizing equipment and facilities. Meat processing industries utilize around 62 Mm^3 of water per year worldwide. The wastewater generated by the slaughterhouse is classified as liquid industrial waste and accounts for 70–75% of the total water consumed in the slaughterhouse.

Wastewater from slaughterhouses includes wastewater from slaughterhouses, intestinal processing, and cleaning of technological premises and stables and must be collected and treated according to the regulations in force. The subject of wastewater management from slaughterhouses, meat processing industry and other sources, has been extensively presented in our previous studies (Ungureanu et al., 2020 a; Ungureanu et al., 2020 b).

In Table 1 we present a summary of the main advantages and disadvantages of the usual methods of waste management in slaughterhouses and meat processing factories.

Table 1. Advantages and disadvantages of slaughterhouse waste management methods

Management method	Advantages	Disadvantages
Burial	It is the predominant choice in cases of catastrophic mortality or infectious disease.	The wrong choice of site (sandy soils or areas with a water table close to the ground surface) leads to significant environmental and health risks.
Composting	It is an economic method by which pathogens from meat waste are inactivated. The resulting compost is an environmentally friendly product. It reduces the risk of water pollution with nitrogen and phosphorus.	Losses of nutrients (nitrogen) occur. Composting landfills require large areas of land. Emissions of odors and greenhouse gases.
Incineration	It is a simple and economical method.	It is one of the major causes of pollutant emissions in the atmosphere (a situation that can be avoided by using high–performance filters).
Incineration with energy recovery	It is the most effective method for destroying infectious agents contained in animal waste and eliminates the risk of spreading diseases. Cremation residues (ash) are non–hazardous and do not attract insects and rodents.	Atmospheric emissions, process control conditions and disposal of liquid and solid residues must be well controlled. It requires auxiliary fuel to initiate and maintain combustion. Smoke and odors can be bothersome. High costs.
Recovery	This method supports the concepts of circular bioeconomy and biorefinery, through which a wide range of products with added value is obtained: energy, fodder, fertilizers, soaps, detergent powder, cosmetics, biofuels, etc.	Emissions of odors and gases. The variety of physico–chemical properties of this type of waste can sometimes be a constraint, as well as a problem for the design and operation of energy systems that utilise this type of waste (incineration, pyrolysis, gasification, anaerobic digestion, etc).

CONCLUSIONS

The existence of the European Commission Regulations and the increase in the costs of disposal of waste and by–products from the meat industry and beyond, led to the implementation of the sustainable development and circular bioeconomy concepts worldwide. Established methods and new technologies are constantly being researched and improved for the recovery of waste and by–products from slaughterhouses and meat processing factories, in various fields such as energy, feed and pet food, fertilizers, chemicals and pharmaceuticals, etc.

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