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MANAGEMENT OF BY–PRODUCTS AND WASTE FROM POULTRY MEAT INDUSTRY

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Abstract: In 2020, the world production of poultry meat was about 136 million tons. All stages of the poultry processing flow generate large amounts of waste and by–products such as hatching remains, poultry litter, bones, fats, trimmings, skin, feathers, organs, viscera, skulls, urine, blood, wastewater, stomach and intestinal contents. These waste are organic in nature, so they decompose quickly and can pollute the environmental factors. This paper aims to highlight some important aspects related to the poultry industry and to analyze each category of waste and by–products generated in the technological flow in poultry slaughterhouses. We also present the current methods of valorizing the waste from poultry meat industry, through which different value–added products are obtained, as routes to align with the concept of sustainable development which aims to achieve food security, environmental protection and energy efficiency.
Keywords: poultry slaughterhouse, blood, wastewater, feathers, offals, valorization

1. ABOUT FOOD WASTE

The food industry is a complex global network that provides most of the food consumed by the world's population. Like water and energy, food is a basic human need. In addition to being available, food must be of high quality, diverse, accessible, safe for consumption and affordable. Food production is carried out with significant energy consumption, and the process results in relatively large amounts of waste due to agricultural practices, improper food transport and storage, and human activities. The two major issues related to food technologies are energy management and waste management (*Dumitru et al., 2020*), which are closely related to the sustainable development of societies worldwide.

The Food and Agriculture Organization of the United Nations (FAO) defines food waste as "any healthy or edible substance that is wasted, lost or degraded in the food supply chain, including organic waste discharged from various sources such as food processing facilities foods, commercial kitchens, canteens and restaurants". The term "food waste" is used broadly and includes by–products or residual products generated at various stages of the food supply chain – the handling, processing and supply of food, including fruit, vegetables, grains, uncooked raw materials and edible materials from markets, as well as wasted food products from homes and restaurants (*Yadav et al., 2016*).

Food waste is often composed of fruit and vegetable residues, molasses and bagasse from sugar refining, bones, meat and blood from meat and fish processing, waste and other residues from wineries, distilleries and breweries, dairy waste, such as cheese whey, and wastewater from washing, bleaching and cooling operations (*Kosseva M.R., 2011*). In industrialized countries, including Europe and North America, significant food waste occurs at the consumption stage, while in less developed and low–income countries, massive food waste is generated mainly in the early and middle stages of the supply chain. Part of the food waste is generated in the context of trying to ensure compliance with the current public health and consumer protection legislation. Contaminated meat withdrawn from the shelves is a waste of resources, but it is also a necessary preventive measure for the protection of human health.

More than 1.3 billion tons of food waste, or approximately 3.3 Gigatons (Gt) of CO_2 equivalent (6% of total greenhouse gases emission) are lost or wasted each year throughout the supply chain, from production to consumption (*Our World in Data, 2020*). According to the United Nations Environment Program, which published in 2021 the new Report on food waste indices, in 2019 approximately 931 million tons of food waste were generated, 61% of which came from households, 26 % of food services and 13% of retail trade. Similarly, in the European Union, households generate more than half of all food waste in the EU (47 million tonnes), and 70% of food waste occurs in households, food services and retail (*unep.org*). In the European Union, the volumes of food waste increased from 89 million tons in 2006 to 126 million tons in 2020.

The Sustainable Development Goals (SDGs) of the Millennium include strategies to reduce climate change and waste management in the agri–food industry. Goal 2 of the 2030 Agenda, "Eradicate hunger, ensure food security, improve nutrition and promote sustainable agriculture" provides that by 2030, to ensure sustainable food production systems and implement resilient agricultural practices that improve productivity and production, which contribute to the maintenance of ecosystems, strengthen the capacity to adapt to climate change, extreme weather, drought, floods and other disasters, and which gradually improve the quality of land

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and soil. The European Union has committed to achieving SDG Target 12.3 to halve per capita food waste at retail and consumer level by 2030 and to reduce food losses along production and food supply. To achieve this goal, today's linear model, based on the principle of "take, make, consume and throw away", must evolve into a circular model. The circular economy model offers a new chance for innovation and integration between natural ecosystems, business, everyday life and waste management.

2. DEVELOPMENT OF THE POULTRY INDUSTRY

In recent years, meat and poultry industry have registered a significant growth (Figure 1). More than 330 million animals (cattle, sheep, pigs and goats) are slaughtered annually in the European Union, resulting in the generation of 18 million tons of meat by–products that must be properly managed to respond to the law in force and to achieve sustainable development. The poultry and eggs production is one of the fastest growing industries worldwide. Relatively low and competitive pricing of poultry meat compared to other meat, the absence of cultural or religious obstacles, and dietary and nutritional (protein) qualities are the main factors of attraction driving the market growth. In 2016, the production of poultry meat accounted for 36% of global meat production (*Kanani et al., 2020*).

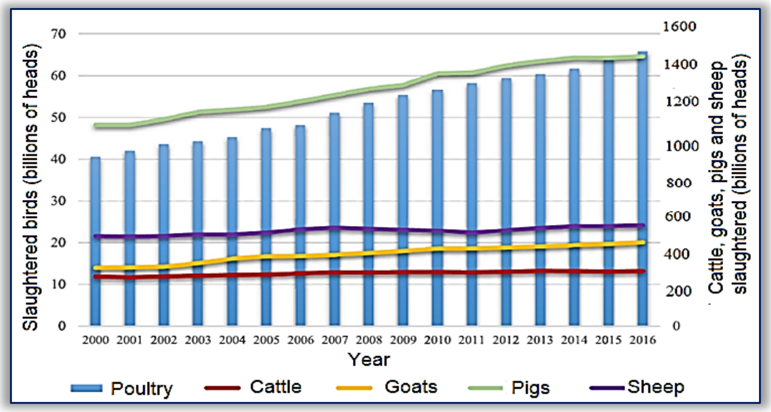

Figure 1 – Global increase in meat production (*Izydorczyk et al., 2022*)

The poultry meat industry grew by 13% between 1961 and 2016. In total, annual global poultry meat production increased from 9 to 120 million tons, while production of poultry for eggs increased from 15 to 81 million tons between 1961 and 2016. In 2019, the European Union produced 13.4 million metric ton of poultry meat. In the total meat produced, about 70% of the production of poultry meat came from just six Member States: 16.8% Poland, 12.9% United Kingdom, 11.4% France, 10.7% Spain, 10.4% Germany, and 8.5% Italy (*Mordor Intelligence*). Also, in 2019, In Europe, the largest poultry slaughterhouses were in France (541 million poultry slaughtered), Netherlands (426 million poultry slaughtered) and Italy (350 million poultry slaughtered) (*Statistica, 2020*). According to the Food and Agriculture Organization (FAO), in 2020, the world production of poultry meat was about 136 million tons, which is 40% of global meat production (*FAO, 2020*). In 2021, there were 376 million laying hens in the EU (372.4 million in 2020) or an increase of 1% (*Poultry World, 2022*).

As many other activities, the global poultry industry was impacted negatively by the COVID–19 pandemic. Poultry breeders in the industrial system were faced with problems in supply chain disruption, particularly to the foodservice sector and volatile feed prices. The European Union has marketing standards for poultry; it imports high value poultry products, including breast meat and poultry preparations, mainly from Brazil, Thailand and Ukraine, and exports poultry products of lower value (*EC, Poultry, 2022*).

3. GENERATION OF BY–PRODUCTS AND WASTE GENERATED IN THE POULTRY MEAT INDUSTRY

Only 60–70% of the poultry slaughterhouse products are edible (*Mezes et al., 2015*). During the slaughtering and processing operations, the meat industry generates large volumes of waste and by–products such as bones, fats, trimmings, skin, hair, organs, viscera, horns, hooves, skulls, urine, blood, wastewater, stomach and intestinal contents. It is estimated that the meat industry generates annually 68 billion tons of litter, blood, bone tissues and feathers (*McGauran et al., 2021*).

In 2009, the European Commission classified waste and animal by–products into 3 categories, in terms of the risk they pose to human and animal health (*EC, Regulation no. 1069/2009*):

- category 1 = waste with special risk or very high risk; these include waste originating from animals likely to be infected with transmissible spongiform encephalopathy (TSE) or animals killed for TSE eradication, and specified risk material respectively. Waste in this category must be destroyed by incineration or co–incineration or can be used to generate biodiesel.
- category 2 = high / medium risk waste; they contain residues of certain substances above the permitted limits or present foreign bodies, dead animals, manure and the contents of the digestive tract of slaughtered animals. Waste in this category is used to obtain fuel, biodiesel, biogas or as fertilizers.
- category 3 = low–risk waste; they include products such as carcasses and parts of slaughtered animals, which are suitable for human consumption, although for commercial reasons they are not ultimately intended for

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human consumption, or are rejected as unfit for human consumption, even if not shows signs of disease transmissible to humans or animals. These waste include bones, hides, skins, horns, feet and blood from ruminants and non–ruminants.

These solid, liquid and gaseous waste have the potential to pollute the environment and endanger human health, so they must be treated and disposed of ecologically. 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. Each category of waste is assigned different disposal methods, for example incineration, pyrolysis, gasification, composting, anaerobic digestion, final disposal.

Regulation no. 142/2011 of the European Commission provides the applicable rules for animal by–products and derived products that are not intended for human consumption. The regulation also specifies the sanitary requirements for the storage, transport and labeling of animal by–products. These by–products must be converted to safe materials before storage or transport.

Air quality, crop production and productivity, water supplies and aquatic organisms are affected by slaughterhouse waste. On the other hand, this waste is a source of energy and nutrients, so it can be recovered through circular economy techniques. The existence of the European Commission Regulations increased the costs of disposal of waste and by–products, and therefore the need to seek applications in different fields such as feed and pet food, energy, fertilizers, chemicals and pharmaceuticals, offering the waste added value and offsetting such costs.

Figure 2 shows the main stages of broiler slaughtering processes, as well as the solid waste or by–products resulting from each stage on the technological flow of the poultry industry. Generation of solid waste starts from the reception stage of the abattoir, to which are added excrements and dead poultry, blood from the bleeding operation, feathers from the jutting operation, organ scraps and intestinal residues from the evisceration operation, as well as bone and inedible meat scraps from cutting and boning operations.

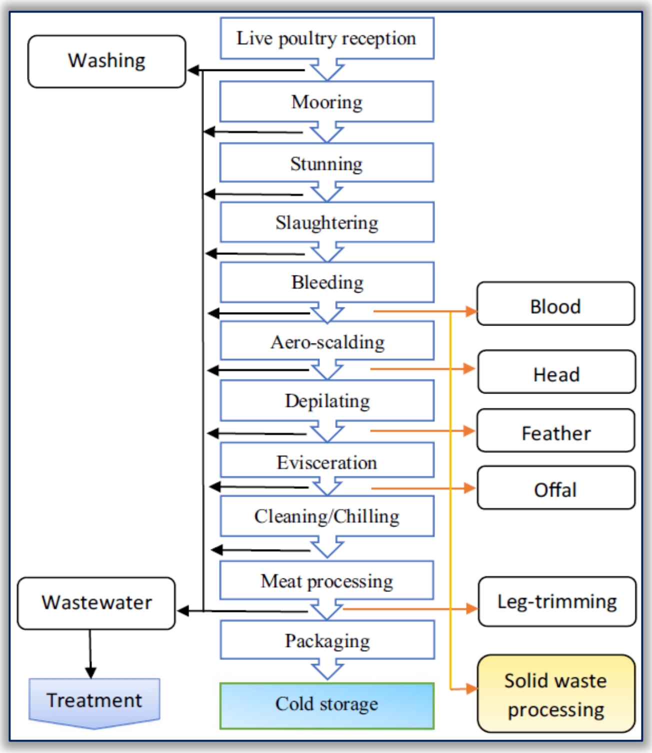

Figure 2 – Technological flow of poultry slaughtering and meat processing *(Yoon et al., 2014; Ozdemir and Yetilmezsoy, 2020)*

By–products, known generically as the edible parts of slaughtered animals and poultry, have the potential to be recovered and used for human consumption, either directly or through further processing.

A typical slaughterhouse with a capacity of 200,000 chickens per day, of an average live weight of 2.3 kg, will produce 127 metric tons of viscera and offal (*Jayathilakan et al., 2012*). The amount of inedible meat offal calculated on the basis of live weight after removal of the salable carcass is 30% of the weight of the live poultry. Poultry slaughterhouse waste contains 52% crude protein, 41% fat, and 6% ash (*Kazemi–Bonchenari et al., 2017*). Poultry offal contain 5.3% total Kjeldahl nitrogen, 32% proteins, 54% lipids and they have 0.6–0.9% methane production potential (*Salminen and Rintala, 2002*).

Since 2002, the use of poultry by–products meals in farmed livestock feed ingredients is banned in the European Union (*EC, Regulation no. 1069/2009*). Meat by–products are traditionally consumed as food or as food ingredients in many countries. Such by–products from the meat industry, such as carcasses, hearts, tongues, liver, kidneys, lungs, contain relevant amounts of nutrients, such as vitamins, minerals and essential amino acids, so that they become nutritious foods or sources of valuable compounds (*Toldra et al., 2021*). Other by–products generated during boning, such as bones, skin, fat and trimmings can be safely used for various applications in a sustainable manner. For example, the skin can be eaten as tapas with fried skin; bones can be boiled to make nutritious and tasty broth (*Toldra et al., 2021*). Separated edible fats can be used 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.

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Animal blood is a fluid obtained on a very large scale, especially in pig and cattle slaughterhouses and less in poultry slaughterhouses. Approximately 3–3.5% live weight blood can be recovered for pigs and 3.3–4% for cattle. Blood is actually sterile in a healthy animal that has been raised without drugs. Blood is a mixture of plasma (up to 60%) and blood cells (about 30–40%), containing about 17–19% proteins of high nutritional value. If blood is hygienically collected and managed in approved slaughterhouses, being cooled to <3°C, then it can be considered suitable for human consumption and treated as a co–product. Animal blood is consumed as part of traditional diet and culture in many countries, being valued, while it may be considered an inedible food in other countries and therefore of much less value.

Table 1. Typical uses of by–products in the poultry meat processing industry (*Jayathilakan et al., 2012*)

By–product	% of live weight	Valorization
Feathers and flakes	7–8	Poultry litter, bionutrient source, feather meal, decorative purpose, yarn and textile applications
Heads	2.5–3	Poultry meal
Blood	3.2–3.7	Blood meal
Stomach and proventricles	3.5–4.2	Edible, source of chitinolytic enzyme
Intestines and glands	8.5–9	Meat meal, poultry fat and active ingredients (hormones and enzymes)
Legs	3.5–4	Soup, technical fat/poultry fat

The amount of waste generated by this sector increases proportionally with animal production.

Solid waste from the poultry industry include waste generated during the hatching (in the hatchery sector) and rearing (bedding materials, hatchery waste and feed mill waste), waste generated during slaughter and meat processing (sludge from flotation and casing for sausages or sausages) and mortality waste. The characteristics of solid waste are presented in Table 2.

Table 2. Physico–chemical composition of waste from the poultry (broiler) production chain

Waste	Total organic carbon (%)	Total Kjeldahl nitrogen (%)	C/N	P (g/kg)	K (g/kg)	Amount (kg dry matter)
Hatchery	12.1	3	4	4.9	1.2	21.3
Feed	50.9	3.7	14	12.7	6.5	10.2
Sausage casing	37.8	0.5	71	8.2	19.2	18.8
Flotation sludge	49.4	7.8	6	45.9	0.7	16.4

Soft waste from poultry slaughterhouses include viscera, intestines, heads, legs, bones, poultry skin, meat scraps and fat, which are not directly suitable for human consumption (*Ferreira et al., 2018*). About 23% of broiler chicken waste is considered soft waste containing head, feet, organs and intestines composed mainly of chicken protein and fat. Improper management of soft waste from slaughterhouses could lead to serious environmental consequences due to their excess organic matter and nutrients. In addition, these new waste are a source of transmission of pathogens, emit unpleasant odors and pose hazards to water, soil and health.

Fats (also known as viscera oil) are primarily obtained from the tissue of poultry and contain Omega–6 fatty acids (is high in linoleic acid) and fat–soluble vitamins. Fats are an indispensable source of animal feed in aquaculture. Adding fats in poultry feeds provides energy to the birds, may change both the composition and the quality of the carcass. *Lara et al. (2003)* found a higher deposition of monounsaturated fatty acids on the carcass of broilers fed with poultry fat when compared to birds fed with raw soybean oil and acidulated soybean oil soapstock. Using fats in poultry feeds also reduces the amount of dust and improves feed texture and color (*Baiao and Lara, 2005*). Fats are also used as ingredient in chemical industry products, and fuel blending agents.

Feathers are protein–rich keratinous waste and constitute up to 7–8% of poultry's total weight, amounting to over 50 g of waste/bird. Worldwide, the poultry meat processing industry generates large amounts of feather by–products, up to 40×10^{9} kg annually (*Tesfaye et al., 2017*). Feathers are mainly made up of 74–91% indigestible keratin protein. In order to solubilize keratin into an easily digestible protein, physical, chemical or biological pretreatments are usually practiced depending on the purpose of further use. A commonly used method is melting by autoclaving above 133°C to release the amino acids (*Ozdemir and Yetilmezsoy, 2020*). Feather meal is generally produced after drying and grinding the hydrolyzed feathers by melting. Biological treatment using *Bacillus licheniformis* to degrade feathers or keratin degrading enzymes is another common method to convert feathers into a digestible protein source (*Mezes et al., 2015*). Due to the unique physicochemical structure such as low density, good flexibility, moderate strength, fineness and length, durability properties, microstructure and thermal stability, feathers are suitable for yarn manufacturing and technical textiles (*Chinta et al., 2013*). Feathers are also often made into feather meal, agricultural fertilizers, bedding or used for decorative purposes.

Wastewater from the slaughterhouse represents 70–75% of the total water consumed in the slaughterhouse (*Azadbakht et al., 2021*). Poultry slaughterhouses discharge massive amounts of wastewater into the environment due to the use of large volumes of fresh water for the continuous operations of cutting, rinsing and packing the meat. Other operations in poultry slaughterhouses such as scalding, feathering, evisceration

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and washing of meat are also water intensive and generate significant amounts of wastewater. For example, 7.57 L of wastewater / poultry are generated in the gutting stage and 4.35 L of wastewater / poultry in the washing stage. According to other studies, on average, between 20.49–26.5 L of clean water is consumed to slaughter one poultry of 2.3 kg.

Wastewater generated in poultry slaughterhouses is highly contaminated with organic matter, measurable by biochemical oxygen demand (BOD_5) and chemical oxygen demand (COD). It also contains nitrogen and phosphorus in high concentrations, blood, fats, oils, fats and proteins. Thus, its discharge of from the poultry slaughterhouse, without being properly treated, has a high risk of polluting fresh water sources. This can cause serious environmental and health problems such as river deoxygenation, groundwater contamination, eutrophication and the spread of waterborne diseases.

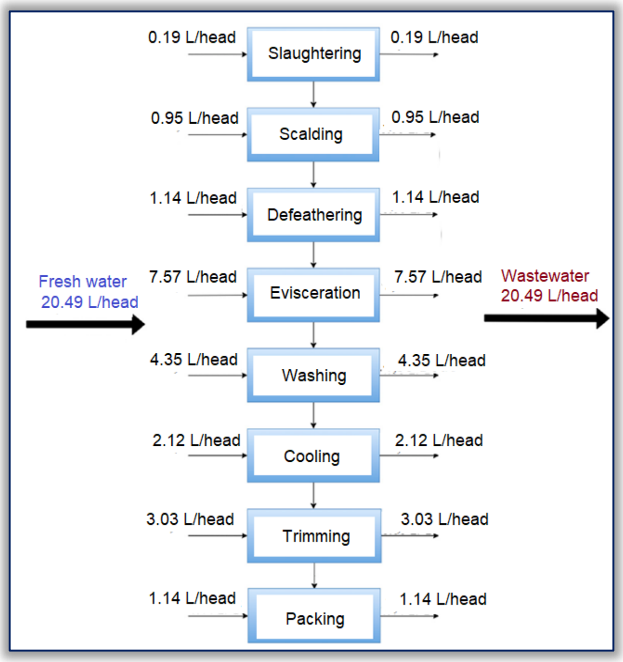

Figure 3 – Water consumption in the poultry slaughterhouse *(Fatima et al., 2021)*

4. MANAGEMENT OF WASTE IN POULTRY MEAT INDUSTRY

In many non–compliant slaughterhouses, the stomach contents and other solid waste are dumped in adjacent authorized areas, and the liquid phase from the washing hall (wastewater containing blood) is allowed to drain into drains. Incorrect management of the various waste streams from poultry slaughter can degrade the soil, water and air quality due to the high load 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)*.

Also, especially in underdeveloped areas, waste from poultry slaughterhouses is simply buried in the ground, without taking measures to protect the environment or considering any method of treatment or recovery. However, current regulations require the sealing of lanfilling pits and the use of biochar for soil and groundwater remediation.

Figure 4 – Solid and liquid waste from a slaughterhouse, improperly stored (*Kefalew and Lami, 2021*)

Figure 5 – Burial of dead poultry and waste from slaughterhouses

Both the disposal of dead and diseased poultry and the transport of poultry waste carry risks of disease transmission. It is a serious problem for the poultry industry, not only from the point of view of environmental protection and biological potential, but also from a financial point of view.

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The treatment of slaughterhouse waste is extremely difficult in urban environments around the world. Low–income countries in particular are experiencing rapid urbanization, which puts enormous pressure on slaughterhouse waste. Lack of properly constructed abattoirs, as well as lack of legislation to restrict and prohibit indiscriminate dumping of hazardous waste, inadequate capacity of waste handlers, poor efficiency of equipment and lack of political commitment and knowledge are the most important causes of inadequate abattoir waste management. In addition, in developing countries, there are insufficient waste management programs and there is a lack of well–organized policies for the disposal of solid and liquid waste produced in slaughterhouses, which are often disposed of without treatment or composting.

European guidelines require that the volumes of waste generated be reduced through valorization technologies that allow the recovery of materials, while the final storage in ecological landfills should be the last option for managing this waste (Figure 6). Each method of disposal of slaughterhouse and meat processing waste has advantages and disadvantages and should be selected accordingly taking into account the waste category. The benefits of using organic waste for energy purposes are in line with global trends in the circular economy. On the other hand, the wide variety of physico–chemical properties of organic waste represents a certain limitation of the energy recovery of waste and a challenge for the design and operation of energy systems that use this type of waste. Uncontrolled incineration of organic waste can pose a threat to the environment and human health due to emissions of carbon oxides, nitrogen and sulphur, dioxins, etc.

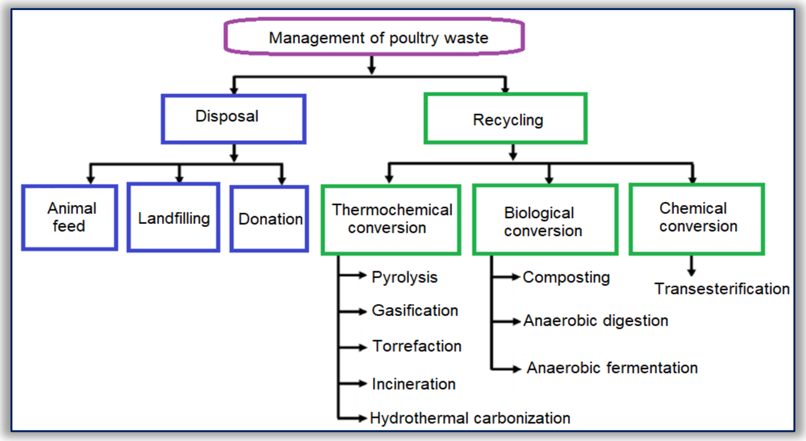

Figure 6 – Some methods of disposal and recycling of poultry waste *(Pour and Makkawi, 2021)*

- *Composting* is a biological method of stabilizing and reducing the mass and volume of organic solid waste due to the oxidation of organic material into CO_2. Waste from the poultry production and processing chain is rich in nutrients and minerals. In many countries, composting is the main biological process used to stabilize these materials. The composting is effective in In addition, the organic compost is used as a natural fertilizer, improving soil characteristics and crop yields. Compost obtained from solid waste from the broiler production chain can also be used as a substrate for the production of seedlings (*Costa et al., 2017*), but it 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 delay in seed germination.
- *Anaerobic digestion*. Bioenergy technology has grown in popularity as more countries adopt the anaerobic digestion as a primary method for treating a wide range of organic waste. In poultry slaughterhouses, one of the main purposes of anaerobic digestion is to reduce the high BOD_5 level of wastewater. Anaerobic digestion consists of hydrolysis, acidogenesis, acetogenesis and methanogenesis steps. In anaerobic conditions, with the help of a diverse group of anaerobic microorganisms (bacteria and archaea), complex organic compounds are decomposed into methane, water and carbon dioxide. Slaughterhouse waste (especially stomach and intestinal contents and blood) is a good substrate for biogas production because it contains a large amount of organic substances (proteins and lipids). Financial benefits, social benefits for climate, health, jobs, but also poverty reduction benefits are all included in the economic benefits of biogas technology. Poultry slaughterhouse waste, rich in protein and lipids, has a high potential to produce large amounts of methane at different concentrations of volatile solids. The hydraulic retention time of this waste in the digester is longer, around 50 days, because of the long–chain fatty acids that hinder methanogenic reactions. Wastewater from poultry slaughterhouses usually has a high organic resistance, which can adversely affect the performance of the anaerobic process. Therefore, an anaerobic treatment system for this wastewater is often followed by additional treatment to remove total phosphorus, total nitrogen, and pathogenic microorganisms. In addition, anaerobic digestion has the potential to produce digestate (organic fertilizer) with excellent nutritional characteristics, with sufficient levels of phosphorus, potassium, calcium, magnesium, manganese, iron and zinc.

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Among the thermal processes for the treatment and recovery of waste and by–products from the meat industry are – burning (incineration), pyrolysis and gasification, 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* is a technology by which poultry waste is thermally decomposed through exothermic oxidation at high temperatures (850–1100°C), and transformed into a non–hazardous, low–volume material, at the same time generating thermal energy, which can be recovered under form of heat (hot water/steam), electricity or a combination thereof. The main disadvantage of incineration is the release of toxic gases and the emission of particles that cause air pollution. A comparative study carried out on the thermal processing of by–products and waste from a poultry slaughterhouse identified the amounts of phosphorus in the residual ash: direct incineration: 53–100 g phosphorus/kg poultry by–products; pyrolysis: 48–73 g phosphorus/kg poultry by–products; gasification: 62 g phosphorus/kg poultry by–products. The residual ash obtained from the incineration of poultry by–products is an ideal product for the production of ecophosphate (monocalcium phosphate), which is an environmentally friendly phosphorus fertilizer. Ecophosphate is an important mineral fertilizer in plant nutrition and can be found in proteins, phytin and organic nucleic acids. Fertilizers containing phosphorus as a main ingredient have a substantial effect on the quality of cultivated plants. Thermo–chemical conversion can be adapted for the management of slaughterhouse waste and by–products with high yields of bio–oil and biochar.
- *Fast pyrolysis*, one of the emerging technologies, 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. Pyrolysis bio–oil can be used as a source of chemicals depending on its characteristics such as water fraction, viscosity, density, chemical composition and pH. Biochar is a coal produced by pyrolysis that can be used as a solid fuel or as a soil conditioner.
- *Gasification* has some similarities with pyrolysis, since both processes involve the thermal decomposition of organic matter to produce hydrocarbons, but, unlike pyrolysis, gasification takes place with the partial oxidation at a higher temperature, in the range of 800–1200°C. Syngas (synthesis gas) is mainly composed of colorless, odorless, highly flammable gases such as CO_2, CO, CH_4, H_2 and a very small fraction of tars. It is commonly used as an energy source, in addition to being an important source of hydrogen and other high–value chemicals.
- *Transesterification*. Feathers, blood and viscera contain up to 12% inedible fat that can be converted into biodiesel, an environmentally friendly biofuel. For this purpose, first the fat is extracted from the waste by scalding it with boiling water (70°C), and fats are transesterified into biodiesel using potassium, nitrogen and methane, processes which generate a yield of 7–11% biodiesel relative to the amount of waste (*Emiroglu et al., 2017*).
- *Soil amendments*. Application of poultry manure as an agricultural soil amendment improves soil water–holding capacity and increases lateral water movement, thereby improving irrigation potential and reducing soil drying. It also increases the number and diversity of soil microorganisms, especially in sandy soils. It has been shown that the continuous application of composted and non–composted poultry manure determines the improvement of the physical properties of degraded soils and contributes to the increase of the yield of agricultural crops, even to a greater extent than the application of biochar and untreated manure (*Are et al., 2017*).
- *Animal feed*. Slaughterhouse waste can also be used as animal feed. Litter from poultry houses is used in diets for poultry, lambs, sheep, pigs, lactating cows, wintering cattle and young cows. Drying of poultry manure is perhaps the oldest waste processing procedure for reuse in animal feed. As manure can be a potential source of pathogenic bacteria (e.g. *Salmonella*), molds and yeasts, feeding poultry waste to livestock depends on the type and standard of poultry management.
- *Feed for insect larvae*. Slaughterhouse waste can also be transformed into feed for raising insect larvae for human consumption or for the biofertilizer industry for agricultural crops (*Allegretti et al., 2018*).
- *Feed for aquaculture*. Aquaculture fish species feed on high–protein and energy–rich feeds (*Yigit et al., 2006; Nenciu et al., 2022*). Pelletized meal from poultry waste could be a very suitable option to support the aquaculture sector that relies heavily on high–quality fishmeal, and to maintain a sustainable environment (*Voicea et al., 2021; Voicea et al., 2022*).

Table 3 shows the comparative advantages and disadvantages of some common methods of waste management from poultry slaughterhouses.

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Table 3. Advantages and disadvantages of slaughterhouse waste management methods (*Singh et al., 2018)*

Management method	Advantages	Disadvantages
Burial	The predominant method in cases of catastrophic mortality or infectious disease.	Poor site selection, such as sandy soils or areas with water tables close to the ground surface, pose environmental and health risks.
Burning	Simple and economical method.	Air pollution and health risks.
Incineration with energy recovery	The most effective method for destroying infectious agents. It eliminates the risk of diseases. Incineration residues are non–hazardous and do not attract insects and rodents.	Air emissions, process conditions and disposal of liquid and solid residues must be well controlled. Requires auxiliary fuel. Smoke and odors can be bothersome. High costs.
Composting	Economical method that kills pathogens. The resulting products are environmentally friendly. It reduces the risk of water pollution with N and P.	Losses of nutrients (N). It requires large areas of land for composting dumps. It emits odors and greenhouse gases.
Recovery	The obtained products can be used as feed or fertilizer. Fatty waste can be used to make soaps, powder detergents, cosmetics, fuels, etc.	Gas emissions and unpleasant odors that can attract insects and rodents to the recovery site.

- *Wastewater treatment*. Preliminary treatment removes suspended solids from wastewater. Rotary drum filters and sieves equipped with a wire mesh retains the solid fraction with a size of 10–30 mm. Rotary sieves also extract solids with diameters greater than 0.5 mm. In pretreatment, 60% of suspended solids and 30% of BOD_5 are removed from slaughterhouse wastewater. Other primary treatment methods include catch basins, flotation, flow equalization. After the preliminary purification, wastewater enters the primary purification stage, in which BOD_5, COD, oil, fats, and total residual solids are removed through various physico–chemical processes. Typical primary treatments are dissolved air flotation, electrocoagulation, coagulation, flocculation and sedimentation. Pollutants present in wastewater that are not removed by primary treatment are further treated by secondary treatment to remove organic compounds and reduce dissolved oxygen levels. In secondary treatment, biological processes are used, namely aerobic digesters (the main purpose of aerobic digestion is nitrification) and anaerobic digesters (to obtain biogas), in which organic matter is degraded into simple compounds.
- *Sludge* from poultry slaughterhouse wastewater treatment is rich in nutrients, hence it could be a feasible substrate for large–scale insect larvae rearing, the larvae can be used as a feed alternative, and their residues can be further used as biofertilizers. It is estimated that a 1200 m^2 poultry house produces about 113 tons of manure annually, and in insect larval rearing systems this amount of waste can be converted into about 65 tons of biofertilizer and about 47 tons of insect larvae for protein production.

5. CONCLUSIONS

Food waste is obtained at every stage of the food chain, from the harvesting of raw materials to post–consumer use. In the circular economy, huge amounts of food waste are considered resources because they generate important energy, chemical and material potentials due to the functionalized molecules they contain. In recent years, collective efforts have been made to exploit food waste as bio resources for the next generation of energy, chemical, pharmaceutical, cosmetic, food and other high value–added products.

In the poultry meat industry, waste is generated from the incubation stage to the packaging and consumption of the meat. Landfilling of waste from poultry slaughterhouses leads to several environmental problems, including leaching, emissions of greenhouse gases (methane) and the production of unpleasant odors. Due to the high moisture content of poultry waste, incineration is an energy–intensive process, often inefficient and causes air pollution. Aerobic composting generates low added value compost, and animal feed production poses risks of disease propagation. Anaerobic digestion is a low–cost and efficient technology for the treatment of poultry waste, producing value–added compounds (methane, hydrogen, and volatile fatty acids), and contributing to environmental sustainability. Conversion of poultry waste into energy is still a challenge, due to its variable heterogeneous composition, high moisture content and low calorific value, which is an impediment to the development of robust, large–scale and efficient industrial processes.

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