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Analysis of modern approaches to the processing of poultry waste and by-products: prospects for use in industrial sectors

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Abstract

Poultry processing is characterized by the accumulation of significant volumes of industrial waste (manure, waste from the incubation and slaughter of poultry, feathers, and carcasses). The overall purpose of this review is to analyze the current global practice of recycling poultry waste and by-products and to study the technological prospects for modifying their properties in terms of obtaining value-added products and preventing environmental pollution. Processing agricultural raw materials in a waste-free production cycle is based on certain economic and ecological aspects. The variety of morphological structures and chemical compositions of by-products and waste allows to obtain valuable components using a wide range of modern processing technologies. The use of recycled waste and by-products of poultry processing varies widely: from applications in food technologies to the production of biofuels. Many researchers strive to develop efficient technologies for converting secondary poultry products; a great deal of attention is paid to enzyme-based technologies, which have been improved significantly.

Keywords: poultry processing; waste; by-product; manure; feather; value-added product.

Practical Application: The main directions of the use of waste and by-products of poultry processing are considered.

1 Introduction

Agriculture plays an important role in the deterioration of the environmental situation. Animal husbandry and poultry farming significantly contribute to environmental pollution in particular. Modern production and processing of poultry are characterized by high numbers of livestock and, as a result, the formation of significant volumes of industrial waste (wastewater, manure, waste from incubation and slaughter of poultry, carcasses, etc.) (Potapov et al., 2020; Potti & Fahad, 2017).

The production and processing of poultry have been found to be relatively environmentally efficient compared to other livestock processing (Ritchie & Roser, 2019). However, research on processes, the development of new devices, and new methods of production waste disposal can serve to reduce the impact on the environment even further (Leinonen et al., 2012).

The problem of recycling by-products and waste from processing agricultural raw materials in a waste-free production cycle is based on the following aspects:

– The costs borne by enterprises for the disposal of hazardous organic waste ultimately lead to an increase in the cost of manufactured products. The increase in global poultry production results in increase the volume of waste up to 68 billion tons per year, including litter, feathers, eggshell, carcass, blood, and wastewater (McGauran et al., 2021). In addition, it is economically feasible to expand resources through deep, complex processing of agricultural raw materials into final products such as feed, fertilizers, and new food ingredients (Belc et al., 2019).

– Waste production is a key environmental issue (Kumar et al., 2018; Jakimiuk et al., 2021). Anaerobic fermentation of organic waste releases significant methane emissions into the atmosphere (Mashur et al., 2021). Dumping waste into the environment or improperly disposed waste from poultry processing pollutes ground and surface water and the air, as a result of which the morbidity of both animals and the population increases. Accordingly, organic waste is a favorable breeding ground for dangerous microorganisms, including pathogenic microorganisms, which can cause great harm to society and the environment (Hubbard et al., 2020).

The rational use of by-products from agricultural raw materials processing is associated with the ecological policies of each country (Khomych et al., 2020).

Considerable quantities of waste and by-products generated during the processing of broiler chickens, as well as in the technological production in the food industry, contain a significant amount of natural polymers and biologically-valuable components. It has been scientifically proven that it is essential to apply comprehensive, effective methods to make full use of animal resources (Galali et al., 2020; Kannah et al., 2020; Voběrkova et al., 2020).

Poultry by-products and waste include bones, viscera, feet, head, blood, and feathers. Poultry processing waste can be divided into several groups depending on their morphological characteristics and biochemical composition (Figure 1).

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The structure and properties of the raw materials determine the specific processing methods, which are presented in a diagram (Figure 2).

In addition to traditional technologies such as composting and incineration, poultry waste is processed by various methods: chemical, physical, microbiological, and complex methods. Currently, a great deal of these materials are processed into meat and bone meal, feather meal, blood meal, and fats through rendering, which is the predominant waste valorization pathway for poultry processing by-products. Many researchers recommend using hydrothermal treatment to treat poultry waste, during which pathogenic microorganisms are deactivated (Dhillon et al., 2017; Lasekan et al., 2013; Vikman et al., 2017; Volik et al., 2017).

Poultry processing by-products are resources not only for obtaining technical and fodder products, but also for the medical and food industry (Tram et al., 2021). Enzymatic hydrolysis,

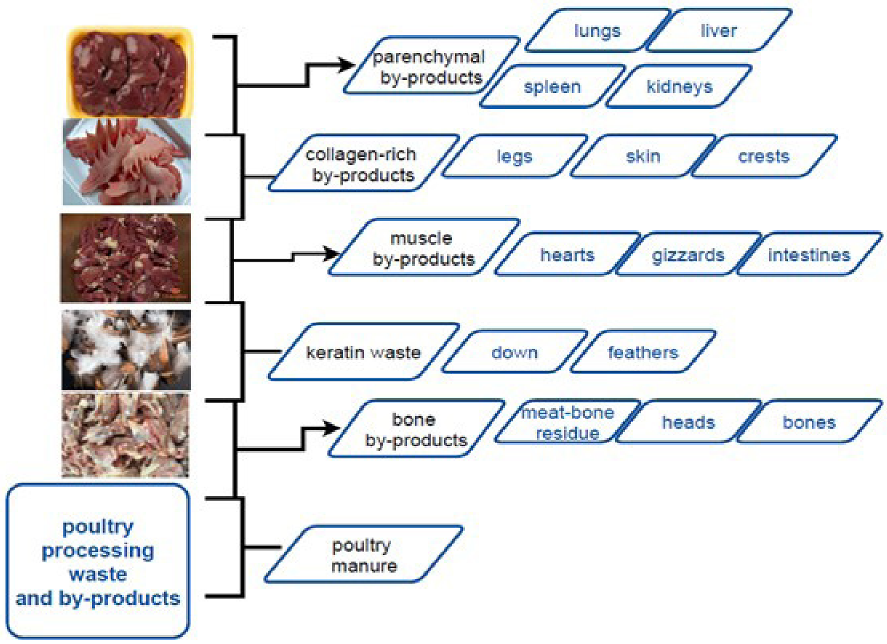

Figure 1. Morphological classification of poultry waste and by-products.

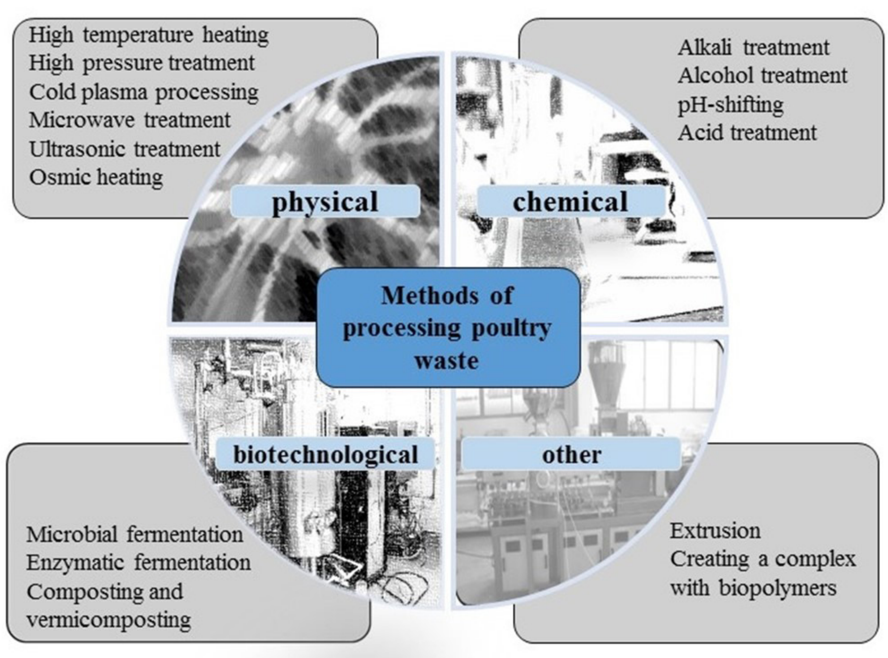

Figure 2. Methods for processing of poultry waste and by-products.

chemical, and thermal treatments of raw materials are used to obtain biologically active compounds, lipids, flavor enhancers, and bioactive peptides (Borrajo et al., 2019; Chakka et al., 2015; Khiari et al., 2014; Rivero-Pino et al., 2020).

At the moment, the world production of poultry meat is about 136 million tons per year (Food and Agriculture Organization, 2021). Taking into account the active growth in the consumption of poultry meat, it is especially important to apply a scientific approach to the processing of secondary raw materials and waste, focusing on the global experience and the achievements of leading researchers in this area. The concept of deep conversion of animal raw materials is worth studying. The overall purpose of this review was to analyze the current global practice of recycling poultry waste and by-products, study the technological prospects for modifying their properties in terms of obtaining value-added products, as well as prevent environmental pollution by poultry industry waste.

2 Directions for processing certain types of waste and by-products

2.1 Manure recycling

As poultry production increases, so does the amount of manure that needs to be processed. When analyzing the types of waste from a chicken farm with 100-150 heads, researchers found that a large share of the waste was manure (98.45%)—fresh manure in particular (73%) (Potapov et al., 2020).

Due to the high content of such components as nitrogen, phosphorus, potassium, and others, poultry manure can be used as a fertilizer to improve soil and increase soil fertility (Fomicheva & Rabinovich, 2021; Samoraj et al., 2022). However, excessive use of poultry manure can harm the soil, water, and air. Uncontrolled removal of poultry manure can lead to emissions of methane, carbon dioxide, and ammonia (Briukhanov et al., 2017; Dróżdż et al., 2020). In addition, manure can contaminate soil and water with potentially hazardous foreign substances such as antibiotics, pesticides, and pathogens (Kyakuwaire et al., 2019). According to the FAO, with a world livestock of 18.5 billion broiler chickens, the amount of nitrogen released into the environment with manure amounted to 6.7 million tons, while the share of manure left on pastures accounted for 40.7%, and the share of processed manure is 58.4% (Food and Agriculture Organization, 2022).

There are biological, physical, chemical, and mixed methods for processing poultry manure (Zapevalov et al., 2019.). Many scientists are aiming to develop new and more efficient technologies for converting poultry manure into energy or value-added products (Feng et al., 2019; Blake & Hess, 2014; Liu et al., 2021). The main applications of poultry manure are as follows:

- enriching soil without preliminary treatment – according to recent studies, this method is undesirable (Kyakuwaire et al., 2019);
- production of organic fertilizers (Feng et al., 2019; Purnomo et al., 2017);
- composting or conversion to biogas (Achi et al., 2020; Hassanein et al., 2019; Ojo et al., 2018; Mehryar et al., 2017);
- production of feed supplements (Blake & Hess, 2014; Jackson et al., 2006);
- conversion to combustion fuel (Zapevalov et al., 2019);
- processing into vermicompost with the help of worms and insects (Subbotina, 2020);
- producing biochar (Liu et al., 2021).

Researchers have noted the possibility of using methane obtained through anaerobic decomposition of manure in household or farmed biogas plants to meet the energy demand (Arthur et al., 2020; Dróżdż et al., 2020; Kanani et al., 2020). There are also studies on the integrated use of poultry manure: first, it is fermented in anaerobic conditions to obtain biogas, then the biogas suspension is subjected to additional processing to obtain fertilizers (Li et al., 2017).

Promising methods for processing poultry manure include the accelerated fermentation of organic raw materials in reactors or fermenters of various designs; extrusion (Fomicheva & Rabinovich, 2021); using an ultrahigh-frequency electromagnetic field for drying and disinfecting (Soboleva et al., 2017). The following technologies of valorization of poultry manure are recommended as priority methods: single-stage anaerobic digestion; anaerobic co-digestion (biological technologies); gasification and fast pyrolysis (thermal technologies) (Kanani et al., 2020). A comparative analysis of poultry manure processing technologies is presented in Table 1.

2.2 Feather processing

Poultry processing produces tens of millions of tons of keratin-containing waste each year (Stiborova et al., 2016). Poultry feathers and down are resources for obtaining additional materials for many industries, such as agro-industrial, food, textile, construction, and many others (Ahmad et al., 2022). Numerous studies report on effective methods for recovering keratin waste (Kshetri et al., 2019).

Feather and down, as a secondary raw material, contain up to 85% protein; converting feather keratin into an easily digestible form is an important task to obtain native protein components. Keratin materials contain a large number of disulfide and hydrogen bonds, hydrophobic interactions, which are difficult to decompose (Bray et al., 2015; McKittrick et al., 2012). High temperature, microwaving, and chemical methods have been explored for the decomposition of feathers (Brebu & Spiridon, 2011; Stiborova et al., 2016). However, aggressive methods of exposure lead to a significant loss of essential amino acids in the product, as well as considerable energy consumption, which imposes a notable burden on the environment (Brebu & Spiridon, 2011; Coward-Kelly et al., 2006).

Recently, enzyme-based technologies have been significantly improved. The efficiency of using new industrial biocatalysts, which includes keratinase obtained by microbiological synthesis, have been proven. Keratinase is widespread in fungi and bacteria;

Table 1. Comparative characteristics of the directions of poultry manure processing.

Direction of use	Advantages	Disadvantages	Reference
Application to the soil without preliminary treatment	Minimum financial costs; enhancing soil physical and hydraulic properties.	Odors and gaseous emissions (ammonia and methane); contamination of soil and water with hazardous substances such as antibiotics, pesticides, and pathogenic microorganisms; prolonged application of poultry manure into the soil can lead to contamination with phosphates and nitrates and cause phytotoxic effects.	Kyakuwaire et al. (2019)
Production of organic fertilizers	Reduction of the bulk and volume density of the soil and penetration resistance; increase in hydraulic conductivity and aggregate stability of the soil; growth of the content of soil organic matter, the content of available water, and the water-holding capacity; increase in the infiltration rate.	Obstacles consist of high moisture content and varying structure of poultry manure; which depend on the type and composition of manure due to seasonality and breeding regime.	Feng et al. (2019); Purnomo et al. (2017)
Composting combined with drying	Effects on rooting young cuttings, mycorrhization and strengthening the root system, insect eradication, biological protection of soil.	This leads to nitrogen loss through ammonia emission; causing emissions into the atmosphere of gaseous products such as methane, ammonia, carbon dioxide; high production costs for drying.	Achi et al. (2020); Hassanein et al. (2019)
Production of feed supplements	Heat treatment reduces the number of pathogenic microorganisms; recycled chicken manure can be used in animal feeding.	The challenge is to produce animal feed that meets the sanitary and veterinary requirements.	Blake & Hess (2014); Jackson et al. (2006)
Using as fuel for combustion	Poultry manure is used as a fuel to generate heat and electricity that can be utilized for the maintenance of poultry houses. This results in the reduction of costs of transportation and an increase in biological safety	High production costs.	Zapevalov et al. (2019)
Generating of the biochar	The increase in temperature promotes the formation and strengthening of the aromatic structure; biochar obtained at a pyrolysis temperature of about 300 oC is suitable for calcareous and acidic soils. Biochars can be used as composting additives, materials for immobilization of heavy metals, sorbents, soil improvers, or carbon sequestration additives.	An increase in temperature caused a decrease in production efficiency. Biochar at 400-500 0C is strongly alkaline, which may limit its use in calcareous soils.	Liu et al. (2021)
Biogas production	Chicken manure is characterized by the high content of dry organic matter – about 80%, which affects the efficient production of biogas and high methane content in biogas.	Low carbon to nitrogen ratio in the poultry manure; as well as the ammonia accumulation during the process, - results in anaerobic decomposition of uric acid and undigested proteins, - the two main forms of nitrogen; ammonium ions and free ammonia can suppress methanogenic activity; high content of hydrogen sulfide reduces the efficiency of anaerobic digestion and requires biogas to be processed before its further use.	Dróżdż et al. (2020); Kanani et al. (2020)

it can convert keratin materials into soluble proteins, antioxidant peptides, and amino acids (Bernal et al., 2018; Peng et al., 2019; Verma et al., 2017).

It is reported that keratinases from *Bacillus subtilis* demonstrated high keratinase activity under extreme conditions, such as high salinity and high temperature (Tork et al., 2013). However, the activity of recombinant keratinase can be greatly enhanced via using genetically modified *Bacillus subtilis* (Peng et al., 2020).

The use of secondary resources of animal origin in modern feed production requires deep processing technologies. Vasilenko et al. (2021) proposed an extrusion technology to obtain a feed protein supplement, which is recommended in the diet of growing poultry, valuable species of fish, and mammals. The technology implements the principle of simultaneous exposure to high temperature and pressure for processing keratin-containing waste. It is noted that extrusion of keratin makes it possible to extract up to 80% of this hard-to-reach dietary protein (Vasilenko et al., 2021).

Protein hydrolysates from down feathers have found application in cosmetology, skincare creams, hair and nail strengthening products, and in the manufacture of detergents. The prospects of industrial application of *Bacillus sp.* CSK2 keratinase are being studied. Researchers have worked to optimize the physicochemical conditions for obtaining CSK2 keratinase from feathers and suggest its application as a bio additive in detergent formulations (Nnolim & Nwodo, 2020). Keratin protein solutions can also be used for medical purposes, such as in bone replacement and bone grafting (Roiter et al., 2019).

The textile industry is a significant consumer of down feathers. The raw material is used as filler in blankets, pillows, and duvets. The highest category of feathers is used to produce coats and overalls, which are light and offer good protection from frost, wind, and moisture. The hydrolyzed feather waste protein can also be used as a modifier to improve the properties of cotton fabric and increase the susceptibility to natural dyes (Zhang et al., 2020).

Consisting of 90% keratin, feathers are a promising resource for the production of biodegradable materials. Ramadhan & Handayani; Ramakrishnan et al., have studied the use of ingredients made from chicken feather keratin in bioplastics manufacturing (Ramadhan & Handayani, 2020; Ramakrishnan et al., 2018). They found that the resulting bioplastic had good mechanical and thermal properties and was proven to be biodegradable. The development of bioplastics from feather waste can solve two problems, namely, reducing the amount of plastic and agro-industrial waste, thereby contributing to environmental sustainability (Ullah et al., 2011). Li et al. performed a complex analysis of biocarbon obtained from chicken feathers under pyrolysis at different temperatures. They concluded that the resulting biocarbon can serve as a cost-effective filler for creating sustainable biobased composites (Li et al., 2020).

Feathers can be used quite effectively in the development of alternative building materials; adding waste feather fibers to fiberboard improved its thermal insulation, sound absorption, and biodegradability (Šafarič et al., 2020).

2.3 By-products processing

Poultry slaughter generates a large amount of by-products, most of which are unsuitable for human consumption. In many countries, poultry by-products such as legs, heads, heart, gizzard, liver are consumed directly or used as part of meat products as an affordable source of animal protein and other essential nutrients (Gorlov et al., 2016; Zhumanova et al., 2018). Another common method for processing secondary raw materials is to use them in the production of feed flour for livestock and poultry (Caires et al., 2010; Silva et al., 2014; Alves et al., 2021). One of the by-products from rendering chicken waste for meal preparation is chicken fat, which is converted into biofuel (Mahyari et al., 2021; Sivamani et al., 2021) or bio lubricant (Hernández-Cruz et al., 2021).

Poultry legs, skin, neck, and bones are used to isolate collagen proteins (Fisinin et al., 2017). High-quality gelatin can be obtained from chicken legs (Almeida et al., 2013). Collagen is isolated from chicken legs in a solution of acetic acid using the proteolytic enzymes papain and pepsin (Hashim et al., 2014). The high yield of collagen from chicken bones is ensured by a multistage isolation technology, which includes the stages: removal of impurities, cleaning, demineralization, degreasing (Cansu & Boran, 2015).

The most rational approach for processing by-products is to choose integrated methods. Mechanical deboning produces more than just meat. Proteins and lipids are obtained from the subsequent enzymatic treatment of the meat-bone residue, and during the final hydrothermal treatment of the residues—phosphorus, calcium, and nitrogen (Vikman et al., 2017).

Enzyme technologies are a promising strategy for waste poultry fat and protein reutilization that combines biodegradation and the production of enzymes from carbon/nitrogen-rich residual biowastes at the same stage and under optimal conditions. The major bioconversion products of poultry waste, biodiesel and bioactivate hydrolysates, can be used as green biofuel and natural bio-additives. Moreover, nutrient-rich animal fat and protein wastes can serve as carbon/nitrogen sources for the growth of enzyme-producing microorganisms (Cheng et al., 2021).

In recent years, the attention of many researchers has been drawn to the production of bioactive peptides from collagen. Different methods are used for the proteolysis of collagen, but the most physiological, enzymatic method of processing raw materials (Iwaniak et al., 2020; Romero-Garay et al., 2020). Poultry skin is rarely processed into valuable products, but there are studies examining its processing methods. A method of extracting collagen with unique functional properties from chicken skin has been proposed (Cliché et al., 2003).

The varied morphological structures and chemical compositions of poultry by-products allows for a wide range of products to be obtained through modern methods of processing and extraction of valuable components (Table 2).

Table 2. Modern technologies for recycling of poultry by-products.

Type of by-product	Treatment method	Final product	Reference
Chicken legs	Extraction using the acetic acid in a concentration from 0.320% to 3.68%, processing time from 1.0 to 8.4 h and extraction temperature from 43.3 °C to 76.8 °C.	Gelatin, collagen films	Santana et al. (2020)
	Extraction of protein, incorporation of sorbitol, and glycerol as a plasticizer.	Edible film	Lee et al. (2015)
	Extraction using NaOH	Gelatin	Saenmuang et al. (2020)
Chicken viscera, giblets	Hydrolysis of raw materials.	Protein hydrolysate for shrimp diets	Soares et al. (2020)
Chicken and turkey heads	Series of batch extractions at different temperatures (50 and 60 °C).	Gelatin	Gál et al. (2020)
Mecha-nically deboned chicken meat residue	Combination alkaline-acid extraction process (60, 70, and 80 °C).	Gelatin	Rammaya et al. (2012)
	Acid concentration of 6.73% and an extraction temperature of 86.8 °C for 1.95 h.	Gelatin	Rafieian et al. (2013)
	48-72 h of enzyme conditioning time, 73-78 °C gelatin extraction temperature, and 100-150 min gelatin extraction time.	Gelatin	Mokrejš et al. (2021)

Table 2. Continued...

Type of by-product	Treatment method	Final product	Reference
Chicken skin	Acetic acid extraction (3% v/v), extraction temperature 60 °C.	Gelatin	Sompie & Triasih (2018)
	Extraction of fat (separate with the basket of the pressure cooker and separate into layers using chloroform), vacuum filtration for oil recovered	Biodiesel	Abid & Touzani (2017)
	Isolation of elastin, preparation of its hydrolyzate using elastase	Elastin-based hydrolysate	Nadalian et al. (2019)
	Fat removal, grinding, and heating up to 40-60 °C, collagen extraction with pepsin or ethylenediamine.	Collagen high in telopeptides	Cliché et al. (2003)
Chicken fat	Transesterification with methanol as alcohol and KOH as the catalyst.	Biodiesel	Mahyari et al. (2021)
	Epoxidation with peracetic acid was generated in situ by using hydrogen peroxide and acetic acid, at 60 °C for 6 h.	Biolubricant	Hernández-Cruz et al. (2021)
Chicken lung	Ultrasound extraction.	Collagen	Zou et al. (2020)
Chicken intestine	Treatment with acetone at the ratio of 1:1.5 (intestine:acetone).	Proteolytic Enzymes with high protease activity	Raj & Mahendrakar (2010)
	Hydrolysis at a reaction temperature of 533 K, reaction time 28 min, H2SO4 concentration in the reagent system 0.02 wt%.	Amino acid	Zhu et al. (2010)
Chicken bone	Low-energy consumption pyrolysis process.	Biochar, adsorbent	Yang et al. (2020)
	Pyrolyze at 600 °C.	Adsorbent for Pb removal in waste water	Park et al. (2019)

3 Conclusion

The poultry processing industry produces a significant amount of by-products and waste containing useful ingredients. Rational processing of raw materials is associated with both environmental and economic benefits. The variety of morphological structures and chemical compositions of poultry by-products allows for the creation of wide range of products through modern methods of processing and extraction of valuable components.

The use of recycled waste and by-products of poultry processing varies widely in different fields: from applications in food technologies to the production of biofuels. Collagen and keratin proteins, which are components of poultry by-products, are a good substrate for the production of hydrolysates and bioactive peptides with various functional properties.

Many researchers strive to develop innovative and efficient technologies for converting secondary poultry products to obtain value-added products; particular attention is paid to enzyme-based technologies, which have been improved significantly. Enzyme technologies are a promising strategy for organic waste reutilization, which solves the issue of environmental pollution and brings economic benefits.

To reduce the risks associated with poultry waste management, it is essential to carry out detailed life cycle assessments to identify and compare the economic potential and environmental benefits of each technology and to consider regional opportunities and limitations to their implementation.

Conflict of interest

The authors declare that they have no conflicts of interest regarding the publication of this manuscript.

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References

Abid, M., & Touzani, M. (2017). First step of waste chicken skin valorization by production of biodiesel in Morocco. *Journal of Materials and Environmental Science*, 8, 2372-2380.

Achi, C. G., Hassanein, A., & Lansing, S. (2020). Enhanced biogas production of cassava wastewater using zeolite and biochar additives and manure co-digestion. *Energies*, 13(2), 491. http://dx.doi.org/10.3390/en13020491.

Ahmad, A., Othman, I., Tardy, B. L., Hasan, S. W., & Banat, F. (2022). Enhanced lactic acid production with indigenous microbiota from date pulp waste and keratin protein hydrolysate from chicken feather waste. *Bioresource Technology Reports*, 18, 101089. http://dx.doi.org/10.1016/j.biteb.2022.101089.

Almeida, P. F., Calarge, F. A., & Santana, J. C. C. (2013). Production of a product similar to gelatin from chicken feet collagen. *Agricultural Engineering*, 33(6), 1289-1300.

Alves, F. E. S. B., Carpiné, D., Teixeira, G. L., Goedert, A. C., Scheer, A. P., & Ribani, R. H. (2021). Valorization of an abundant slaughterhouse by-product as a source of highly technofunctional and antioxidant protein hydrolysates. *Waste and Biomass Valorization*, 12(1), 263-279. http://dx.doi.org/10.1007/s12649-020-00985-8.

Arthur, R., Baidoo, M. F., Osei, G., Boamah, L., & Kwofie, S. (2020). Evaluation of potential feedstocks for sustainable biogas production in Ghana: quantification, energy generation, and CO_2abatement. *Cogent Environmental Science*, 6(1), 1868162. http://dx.doi.org/10.1080/23311843.2020.1868162.

Belc, N., Mustatea, G., Apostol, L., Iorga, S., Vlăduţ, V.-N., & Mosoiu, C. (2019). Cereal supply chain waste in the context of circular economy. *E3S Web of Conferences*, 112, 03031. http://dx.doi.org/10.1051/e3sconf/201911203031.

Bernal, C., Rodríguez, K., & Martínez, R. (2018). Integrating enzyme immobilization and protein engineering: an alternative path for the development of novel and improved industrial biocatalysts. *Biotechnology Advances*, 36(5), 1470-1480. http://dx.doi.org/10.1016/j.biotechadv.2018.06.002. PMid:29894813.

Blake, J., & Hess, J. (2014). Suitability of poultry litter ash as a feed supplement for broiler chickens. *Journal of Applied Poultry Research*, 23(1), 94-100. http://dx.doi.org/10.3382/japr.2013-00836.

Borrajo, P., Pateiro, M., Barba, F. J., Mora, L., Franco, D., Toldrá, F., & Lorenzo, M. J. (2019). Antioxidant and antimicrobial activity of peptides extracted from meat by-products: a review. *Food Analytical Methods*, 12(11), 2401-2415. http://dx.doi.org/10.1007/s12161-019-01595-4.

Bray, D. J., Walsh, T. R., Noro, M. G., & Notman, R. (2015). Complete structure of an epithelial keratin dimer: implications for intermediate filament assembly. *PLoS One*, 10(7), e0132706. http://dx.doi.org/10.1371/journal.pone.0132706. PMid:26181054.

Brebu, M., & Spiridon, I. (2011). Thermal degradation of keratin waste. *Journal of Analytical and Applied Pyrolysis*, 91(2), 288-295. http://dx.doi.org/10.1016/j.jaap.2011.03.003.

Briukhanov, A., Subbotin, I., Uvarov, R., & Vasilev, E. (2017). Method of designing of manure utilization technology. *Agronomy Research*, 15(3), 658-663.

Caires, C. M. I., Fernandes, E. A., Fagundes, N. S., Carvalho, A. P., Maciel, M. P., & Oliveira, B. R. (2010). The use of animal byproducts in broiler feeds. Use of animal co-products in broilers diets. *Revista Brasileira de Ciência Avícola*, 12(1), 41-46. http://dx.doi.org/10.1590/S1516-635X2010000100006.

Cansu, Ü., & Boran, G. (2015). Optimization of a multi-step procedure for isolation of chicken bone collagen. *Korean Journal for Food Science of Animal Resources*, 35(4), 431-440. http://dx.doi.org/10.5851/kosfa.2015.35.4.431. PMid:26761863.

Chakka, A. K., Elias, M., Jini, R., Sakhare, P. Z., & Bhaskar, N. (2015). In-vitro antioxidant and antibacterial properties of fermentatively and enzymatically prepared chicken liver protein hydrolysates. *Journal of Food Science and Technology*, 52(12), 8059-8067. http://dx.doi.org/10.1007/s13197-015-1920-2. PMid:26604378.

Cheng, D., Liu, Y., Ngo, H. H., Guo, W., Chang, S. W., Nguyen, D. D., Zhang, S., Luo, G., & Bui, X. T. (2021). Sustainable enzymatic technologies in waste animal fat and protein management. *Journal of Environmental Management*, 284, 112040. http://dx.doi.org/10.1016/j.jenvman.2021.112040. PMid:33571854.

Cliché, S., Amiot, J., Avezard, C., & Gariepy, C. (2003). Extraction and characterization of collagen with or without telopeptides from chicken skin. *Poultry Science*, 82(3), 503-509. http://dx.doi.org/10.1093/ps/82.3.503. PMid:12705413.

Coward-Kelly, G., Chang, V. S., Agbogbo, F. K., & Holtzapple, M. T. (2006). Lime treatment of keratinous materials for the generation of highly digestible animal feed: chicken feathers. *Bioresource Technology*, 97(11), 1337-1343. http://dx.doi.org/10.1016/j.biortech.2005.05.021. PMid:16098740.

Dhillon, G. S., Kaur, S., Oberoi, H. S., Spier, M. R., & Brar, S. K. (2017). Agricultural-based protein by-products: characterization and applications. In G. S. Dhillon (Ed.), *Protein byproducts: transformation from environmental burden into value-added products* (pp. 21-36). Edmonton: Academic Press.

Dróżdż, D., Wystalska, K., Malinska, K., Grosser, A., Grobelak, A., & Kacprzak, M. (2020). Management of poultry manure in Poland – current state and future perspectives. *Journal of Environmental Management*, 264, 110327. http://dx.doi.org/10.1016/j.jenvman.2020.110327. PMid:32217329.

Feng, G., Adeli, A., Read, J., McCarty, J., & Jenkins, J. (2019). Consequences of pelletized poultry litter applications on soil physical and hydraulic properties in reduced tillage, continuous cotton system. *Soil & Tillage Research*, 194, 104309. http://dx.doi.org/10.1016/j.still.2019.104309.

Fisinin, V. I., Ismailova, D. Y., Volik, V. G., Lukashenko, V. S., & Saleeva, I. P. (2017). Deep processing of collagen-rich poultry products for different use. *Agricultural Biology*, 52(6), 1105-1115. http://dx.doi.org/10.15389/agrobiology.2017.6.1105eng.

Fomicheva, N. V., & Rabinovich, G. Y. (2021). Technological line for processing animal waste. *IOP Conference Series: Earth and Environmental Science*, 677, 052004.

Food and Agriculture Organization – FAO. (2021). *Gateway to poultry production and products*. Retrieved from http://www.fao.org/poultry-production-products/production/en/

Food and Agriculture Organization – FAO. (2022). *Crops and livestock products*. Retrieved from https://www.fao.org/faostat/en/#data/QCL

Gál, R., Mokrejš, P., Mrázek, P., Pavlačková, J., Janáčová, D., & Orsavová, J. (2020). Chicken heads as a promising by-product for preparation of food gelatins. *Molecules*, 25(3), 494. http://dx.doi.org/10.3390/molecules25030494. PMid:31979349.

Galali, Y., Omar, Z. A., & Sajadi, S. M. (2020). Biologically active components in by-products of food processing. *Food Science & Nutrition*, 8(7), 3004-3022. http://dx.doi.org/10.1002/fsn3.1665. PMid:32724565.

Gorlov, I. F., Giro, T. M., Sitnikova, O. I., Slozhenkina, M. I., Zlobina, E. Y., & Karpenko, E. V. (2016). New functional products with chickpeas: reception, functional properties. *American Journal of Food Technology*, 11(6), 273-281. http://dx.doi.org/10.3923/ajft.2016.273.281.

Hashim, P., Ridzwan, M. S. M., & Bakar, J. (2014). Isolation and characterization of collagen from chicken feet. *International Journal of Bioengineering and Life Sciences*, 8(3), 250-254.

Hassanein, A., Lansing, S., & Tikekar, R. (2019). Impact of metal nanoparticles on biogas production from poultry litter. *Bioresource Technology*, 275, 200-206. http://dx.doi.org/10.1016/j.biortech.2018.12.048. PMid:30590206.

Hernández-Cruz, M. C., Meza-Gordillo, R., Domínguez, Z., Rosales-Quintero, A., Abud-Archila, M., Ayora-Talavera, T., & Villalobos-Maldonado, J. J. (2021). Optimization and characterization of in situ epoxidation of chicken fat with peracetic acid. *Fuel*, 285, 119127. http://dx.doi.org/10.1016/j.fuel.2020.119127.

Hubbard, L. E., Givens, C. E., Griffin, D. W., Iwanowicz, L. R., Meyer, M. T., & Kolpin, D. W. (2020). Poultry litter as potential source of pathogens and other contaminants in groundwater and surface water proximal to large-scale confined poultry feeding operations. *The Science of the Total Environment*, 735, 139459. http://dx.doi.org/10.1016/j.scitotenv.2020.139459. PMid:32485450.

Iwaniak, A., Minkiewicz, P., Pliszka, M., Mogut, D., & Darewicz, M. (2020). Characteristics of biopeptides released in silico from collagens using quantitative parameters. *Foods*, 9(7), 965. http://dx.doi.org/10.3390/foods9070965. PMid:32708318.

Jackson, D. J., Rude, B. J., Karanja, K. K., & Whitley, N. C. (2006). Utilization of poultry litter pellets in meat goat diets. *Small Ruminant Research*, 66(1-3), 278-281. http://dx.doi.org/10.1016/j.smallrumres.2005.09.005.

Jakimiuk, A., Vaverková, M. D., & Maxianová, A. (2021). Food waste – challenges and approaches for new devices journal of ecological engineering. *Journal of Ecological Engineering*, 22(3), 231-238. http://dx.doi.org/10.12911/22998993/132430.

Kanani, F., Heidari, M. D., Gilroyed, B. H., & Pelletier, N. (2020). Waste valorization technology options for the egg and broiler industries: a review and recommendations. *Journal of Cleaner Production*, 262, 121129. http://dx.doi.org/10.1016/j.jclepro.2020.121129.

Kannah, R. Y., Merrylin, J., Devi, T. P., Kavitha, S., Sivashanmungam, P., Kumar, G., & Banu, J. R. (2020). Food waste valorization: biofuels and value added product recovery. *Bioresource Technology Reports*, 11, 100524. http://dx.doi.org/10.1016/j.biteb.2020.100524.

Khiari, Z., Ndagijimana, M., & Betti, M. (2014). Low molecular weight bioactive peptides derived from the enzymatic hydrolysis of collagen after isoelectric solubilization/precipitation process of turkey by-products. *Poultry Science*, 93(9), 2347-2362. http://dx.doi.org/10.3382/ps.2014-03953. PMid:24931971.

Khomych, G., Krusir, G., Horobets, O., Levchenko, Y., & Gaivoronska, Z. (2020). Development of resource effective and cleaner technologies using the waste of plant raw materials. *Journal of Ecological Engineering*, 21(4), 178-184. http://dx.doi.org/10.12911/22998993/119814.

Kshetri, P., Roy, S. S., Sharma, S. K., Singh, T. S., Ansari, M. A., Prakash, N., & Ngachan, S. (2019). Transforming chicken feather waste into feather protein hydrolysate using a newly isolated multifaceted keratinolytic bacterium Chryseobacterium sediminis RCM-SSR-7. *Waste and Biomass Valorization*, 10(1), 1-11. http://dx.doi.org/10.1007/s12649-017-0037-4.

Kumar, S., Negi, S., Mandpe, A., Singh, R. V., & Hussain, A. (2018). Rapid composting techniques in Indian context and utilization of black soldier fly for enhanced decomposition of biodegradable wastes – a comprehensive review. *Journal of Environmental Management*, 227, 189-199. http://dx.doi.org/10.1016/j.jenvman.2018.08.096. PMid:30193208.

Kyakuwaire, M., Olupot, G., Amoding, A., Nkedi-Kizza, P., & Basamba, T. A. (2019). How safe is chicken litter for land application as an organic fertilizer? A review. *International Journal of Environmental Research and Public Health*, 16(19), 3521. http://dx.doi.org/10.3390/ijerph16193521. PMid:31547196.

Lasekan, A., Bakar, F. A., & Hashim, D. (2013). Potential of chicken byproducts as sources of useful biological resources. *Waste Management*, 33(3), 552-565. http://dx.doi.org/10.1016/j.wasman.2012.08.001. PMid:22985619.

Lee, J. H., Lee, J., & Song, K. B. (2015). Development of a chicken feet protein film containing essential oils. *Food Hydrocolloids*, 46, 208-215. http://dx.doi.org/10.1016/j.foodhyd.2014.12.020.

Leinonen, I., Williams, A. G., Wiseman, J., Guy, J., & Kyriazakis, I. (2012). Predicting the environmental impacts of chicken systems in the United Kingdom through a life cycle assessment: broiler production systems. *Poultry Science*, 91(1), 8-25. http://dx.doi.org/10.3382/ps.2011-01634. PMid:22184424.

Li, P., Zhang, C. J., Zhao, T. K., & Zhong, H. (2017). Removal of suspended solids in anaerobically digested slurries of livestock and poultry manure by coagulation using different dosages of polyaluminum chloride. In M. Gibson & Y. Fan (Eds.), *2016 International Conference on Environmental Engineering and Sustainable Development* (p. 012008). Bristol: IOP Publishing. http://dx.doi.org/10.1088/1742-6596/51/1/012008.

Li, Z., Reimer, C., Picard, M., Mohanty, A. K., & Misra, M. (2020). Characterization of chicken feather biocarbon for use in sustainable biocomposites. *Frontiers in Materials*, 7, 3. http://dx.doi.org/10.3389/fmats.2020.00003.

Liu, C., Yin, Z., Hu, D., Mo, F., Chu, R., Zhu, L., & Hu, C. (2021). Biochar derived from chicken manure as a green adsorbent for naphthalene removal. *Environmental Science and Pollution Research International*, 28(27), 36585-36597. http://dx.doi.org/10.1007/s11356-021-13286-x. PMid:33704645.

Mahyari, Z. F., Khorasanizadeh, Z., Khanali, M., & Mahyari, K. F. (2021). Biodiesel production from slaughter wastes of broiler chicken: a potential survey in Iran. *SN Applied Sciences*, 3(1), 57. http://dx.doi.org/10.1007/s42452-020-04045-7.

Mashur, M., Bilad, M. R., Hunaepi, H., Huda, N., & Roslan, J. (2021). Formulation of organic wastes as growth media for cultivation of earthworm nutrient-rich *Eisenia foetida*. *Sustainability*, 13(18), 10322. http://dx.doi.org/10.3390/su131810322.

McGauran, T., Dunne, N., Smyth, B. M., & Cunningham, E. (2021). Feasibility of the use of poultry waste as polymer additives and implications for energy, cost and carbon. *Journal of Cleaner Production*, 291, 125948. http://dx.doi.org/10.1016/j.jclepro.2021.125948.

McKittrick, J., Chen, P. Y., Bodde, S. G., Yang, W., Novitskaya, E. E., & Meyers, M. A. (2012). The structure, functions, and mechanical properties of keratin. *JOM*, 64(4), 449-468. http://dx.doi.org/10.1007/s11837-012-0302-8.

Mehryar, E., Ding, W. M., Hemmat, A., Hassan, M., Bi, J. H., Huang, H. Y., & Kafashan, J. (2017). Anaerobic co-digestion of oil refinery wastewater and chicken manure to produce biogas, and kinetic parameters determination in batch reactors. *Agronomy Research*, 15(5), 1983-1996.

Mokrejš, P., Gál, R., Pavlačková, J., & Janáčová, D. (2021). Valorization of a by-product from the production of mechanically deboned chicken meat for preparation of gelatins. *Molecules*, 26(2), 349. http://dx.doi.org/10.3390/molecules26020349. PMid:33445455.

Nadalian, M., Kamaruzaman, N., Yusop, M. S. M., Babji, A. S., & Yusop, S. M. (2019). Isolation, purification and characterization of antioxidative bioactive elastin peptides from poultry skin. *Food Science of Animal Resources*, 39(6), 966-979. http://dx.doi.org/10.5851/kosfa.2019.e90. PMid:31950112.

Nnolim, N. E., & Nwodo, U. U. (2020). *Bacillus sp. CSK2* produced thermostable alkaline keratinase using agro-wastes: keratinolytic enzyme characterization. *BMC Biotechnology*, 20(1), 65. http://dx.doi.org/10.1186/s12896-020-00659-2. PMid:33317483.

Ojo, A. O., Taiwo, L. B., Adediran, J. A., Oyedele, A. O., Fademi, I., & Uthman, A. C. O. (2018). Physical, chemical and biological properties of an accelerated cassava based compost prepared using different ratios of cassava peels and poultry manure. *Communications in Soil Science and Plant Analysis*, 49(14), 1774-1786. http://dx.doi.org/10.1080/00103624.2018.1474914.

Park, J. H., Wang, J. J., Kim, S. H., Kang, S. W., Cho, J. S., Delaune, R. D., Ok, Y. S., & Seo, D. C. (2019). Lead sorption characteristics of various chicken bone part-derived chars. *Environmental Geochemistry and Health*, 41(4), 1675-1685. http://dx.doi.org/10.1007/s10653-017-0067-7. PMid:29344748.

Peng, Z., Mao, X., Zhang, J., Du, G., & Chen, J. (2019). Effective biodegradation of chicken feather waste by co-cultivation of keratinase producing strains. *Microbial Cell Factories*, 18(1), 84. http://dx.doi.org/10.1186/s12934-019-1134-9. PMid:31103032.

Peng, Z., Mao, X., Zhang, J., Du, G., & Chen, J. (2020). Biotransformation of keratin waste to amino acids and active peptides based on cell-free catalysis. *Biotechnology for Biofuels*, 13(1), 61. http://dx.doi.org/10.1186/s13068-020-01700-4. PMid:32266007.

Potapov, M. A., Kurochkin, A. A., & Frolov, D. I. (2020). Equalization of the moisture content of the mixture for obtaining fertilizers from high-moisture waste of poultry farming by extrusion. *IOP Conference*

Series. Materials Science and Engineering, 1001(1), 012029. http://dx.doi.org/10.1088/1757-899X/1001/1/012029.

Potti, R. B., & Fahad, M. O. (2017). Extraction and characterization of collagen from broiler chicken feet (Gallus gallus domesticus)-biomolecules from poultry waste. *Journal of Pure & Applied Microbiology*, 11(1), 315-322. http://dx.doi.org/10.22207/JPAM.11.1.39.

Purnomo, C. W., Indarti, S., Wulandari, C., Hinode, H., & Nakasaki, K. (2017). Slow release fertiliser production from poultry manure. *Chemical Engineering Transactions*, 56, 1531-1536.

Rafieian, F., Keramat, J., & Kadivar, M. (2013). Optimization of gelatin extraction from chicken deboner residue using RSM method. *Journal of Food Science and Technology*, 50(2), 374-380. http://dx.doi.org/10.1007/s13197-011-0355-7. PMid:24425930.

Raj, K. R., & Mahendrakar, N. S. (2010). Effect of ensiling and organic solvents treatment on proteolytic enzymes of layer chicken intestine. *Journal of Food Science and Technology*, 47(3), 320-324. http://dx.doi.org/10.1007/s13197-010-0051-z. PMid:23572645.

Ramadhan, M. O., & Handayani, M. N. (2020). The potential of food waste as bioplastic material to promote environmental sustainability: a review. *IOP Conference Series. Materials Science and Engineering*, 980(1), 012082. http://dx.doi.org/10.1088/1757-899X/980/1/012082.

Ramakrishnan, N., Sharma, S., Gupta, A., & Alashwal, B. Y. (2018). Keratin based bioplastic film from chicken feathers and its characterization. *International Journal of Biological Macromolecules*, 111, 352-358. http://dx.doi.org/10.1016/j.ijbiomac.2018.01.037. PMid:29320725.

Rammaya, K., Ying, V. Q., & Babji, A. S. (2012). Physicochemical analysis of gelatin extracted from mechanically deboned chicken meat (MDCM) residue. *International Journal of Food, Nutrition and Public Health*, 5(1-2-3), 147-168. http://dx.doi.org/10.47556/J.IJFNPH.5.1-2-3.2012.9.

Ritchie, H., & Roser, M. (2019). Meat and dairy production. *Our World in Data*. Online. Retrieved from https://ourworldindata.org/meat-production#citation

Rivero-Pino, F., Espejo-Carpio, F. J., & Guadix, E. M. (2020). Antidiabetic food-derived peptides for functional feeding: production, functionality and in vivo evidences. *Foods*, 9(8), 983. http://dx.doi.org/10.3390/foods9080983. PMid:32718070.

Roiter, L. M., Zazykina, L. A., & Eremeeva, N. A. (2019). Poultry by-products, reserve for growth of export potential of the industry. *IOP Conference Series: Earth and Environmental Science*, 341, 012209. http://dx.doi.org/10.1088/1755-1315/341/1/012209.

Romero-Garay, M. G., Martínez-Montaño, E., Hernández-Mendoza, A., Vallejo-Cordoba, B., González-Córdova, A. F., Montalvo-González, E., & García-Magaña, M. L. (2020). *Bromelia karatas* and *Bromelia pinguin*: sources of plant proteases used for obtaining antioxidant hydrolysates from chicken and fish by-products. *Applied Biological Chemistry*, 63(1), 41. http://dx.doi.org/10.1186/s13765-020-00525-x.

Saenmuang, S., Phothiset, S., & Chumnanka, C. (2020). Extraction and characterization of gelatin from black-bone chicken by-products. *Food Science and Biotechnology*, 29(4), 469-478. http://dx.doi.org/10.1007/s10068-019-00696-4. PMid:32296557.

Šafarič, R., Zemljič, L. F., Novak, M., Dugonik, B., Bratina, B., Gubeljak, N., Bolka, S., & Strnad, S. (2020). Preparation and characterisation of waste poultry feathers composite fibreboards. *Materials*, 13(21), 4964. http://dx.doi.org/10.3390/ma13214964. PMid:33158218.

Samoraj, M., Mironiuk, M., Izydorczyk, G., Witek-Krowiak, A., Szopa, D., Moustakas, K., & Chojnacka, K. (2022). The challenges and perspectives for anaerobic digestion of animal waste and fertilizer application of the digestate. *Chemosphere*, 295, 133799. http://dx.doi.org/10.1016/j.chemosphere.2022.133799. PMid:35114259.

Santana, J. C. C., Gardim, R. B., Almeida, P. F., Borini, G. B., Quispe, A. P. B., Llanos, S. A. V., Heredia, J. A., Zamuner, F. M. C., Gamarra, S., Farias, T. M. B., Ho, L. L., & Berssaneti, F. T. (2020). Valorization of chicken feet by-product of the poultry industry: high qualities of gelatin and biofilm from extraction of collagen. *Polymers*, 12(3), 529. http://dx.doi.org/10.3390/polym12030529. PMid:32121646.

Silva, E. P., Rabello, C. B.-V., Lima, M. B., Ludke, J. V., Arruda, E. M. F., & Albino, L. F. T. (2014). Poultry offal meal in broiler chicken feed. *Scientia Agrícola*, 71(3), 188-194. http://dx.doi.org/10.1590/S0103-90162014000300003.

Sivamani, S., Manickam, A., Karthiban, S., Karthikeyan, S., & Balajii, M. (2021). Process modelling and simulation of biodiesel synthesis reaction for non-edible yellow oleander (yellow bells) oil and waste chicken fat. In M. Srivastava, N. Srivastava & R. Singh (Eds.), *Bioenergy research: revisiting latest development.* (pp. 129-160). Singapore: Springer. http://dx.doi.org/10.1007/978-981-33-4615-4_6.

Soares, M., Rezende, P. C., Corrêa, N. M., Rocha, J. S., Martins, M. A., Andrade, T. C., Fracalossi, D. M., & Vieira, F. N. (2020). Protein hydrolysates from poultry by-product and swine liver as an alternative dietary protein source for the Pacific white shrimp. *Aquaculture Reports*, 17, 100344. http://dx.doi.org/10.1016/j.aqrep.2020.100344.

Soboleva, O. M., Kolosova, M. M., Filipovich, L. A., & Aksenov, V. A. (2017). Electromagnetic processing as a way of increasing microbiological safety of animal waste. *IOP Conference Series: Earth and Environmental Science*, 66, 012025. http://dx.doi.org/10.1088/1755-1315/66/1/012025.

Sompie, M., & Triasih, A. (2018). Effect of extraction temperature on characteristics of chicken legskin gelatin. *IOP Conference Series: Earth and Environmental Science*, 102, 012089. http://dx.doi.org/10.1088/1755-1315/102/1/012089.

Stiborova, H., Branska, B., Vesela, T., Lovecka, P., Stranska, M., Hajslova, J., Jiru, M., Patakova, P., & Demnerova, K. (2016). Transformation of raw feather waste into digestible peptides and amino acids. *Journal of Chemical Technology and Biotechnology*, 91(6), 1629-1637. http://dx.doi.org/10.1002/jctb.4912.

Subbotina, Y. M. (2020). Microbiological and biocenotic utilization of bird droppings by natural biocenoses. *Problems of Veterinary Sanitation, Hygiene and Ecology*, 1(3), 341-350. http://dx.doi.org/10.36871/vet.san.hyg.ecol.202003009.

Tork, S. E., Shahein, Y. E., El-Hakim, A. E., Abdel-Aty, A. M., & Aly, M. M. (2013). Production and characterization of thermostable metallo-keratinase from newly isolated *Bacillus subtilis NRC 3. International Journal of Biological Macromolecules*, 55, 169-175. http://dx.doi.org/10.1016/j.ijbiomac.2013.01.002. PMid:23313822.

Tram, N. X. T., Ishikawa, K., Minh, T. H., Benson, D., & Tsuru, K. (2021). Characterization of carbonate apatite derived from chicken bone and its in-vitro evaluation using MC3T3-E1 cells. *Materials Research Express*, 8(2), 025401. http://dx.doi.org/10.1088/2053-1591/abe018.

Ullah, A., Vasanthan, T., Bressler, D., Elias, A. L., & Wu, J. (2011). Bioplastics from feather quill. *Biomacromolecules*, 12(10), 3826-3832. http://dx.doi.org/10.1021/bm201112n. PMid:21888378.

Vasilenko, V. N., Frolova, L. N., Mikhailova, N. A., & Dragan, I. V. (2021). Innovative technology to obtain forage flour from keratincontaining waste by extrusion. *IOP Conference Series: Earth and Environmental Science*, 640, 022010.

Verma, A., Singh, H., Anwar, S., Chattopadhyay, A., Tiwari, K. K., Kaur, S., & Dhilon, G. S. (2017). Microbial keratinases: industrial enzymes with waste management potential. *Critical Reviews in Biotechnology*, 37(4), 476-491. http://dx.doi.org/10.1080/07388551.2016.1185388. PMid:27291252.

Vikman, Y. M., Siipola, V., Kanerva, H., Šližyte, R., & Wikberg, H. (2017). Poultry by-products as a potential source of nutrients. *Advances in Recycling and Waste Management*, 2(3), 1000142.

Voběrkova, S., Maxianová, A., Schlosserová, N., Adamcová, D., Vršanská, M., Richtera, L., Gagić, M., Zloch, J., & Vaverková, M. D. (2020). Food waste composting. Is it really so simple as stated in scientific literature? A case study. *The Science of the Total Environment*, 723, 138202. http://dx.doi.org/10.1016/j.scitotenv.2020.138202. PMid:32224413.

Volik, V. G., Ismailova, D. Y., Zinoviev, S. V., & Erokhina, O. N. (2017). Improving the efficiency of using secondary raw materials obtained during poultry processing. *Poultry and Poultry Products*, 2, 40-42.

Yang, T., Han, C., Tang, J., & Luo, Y. (2020). Removal performance and mechanisms of Cr(VI) by an in-situ self-improvement of mesoporous biochar derived from chicken bone. *Environmental Science and Pollution Research International*, 27(5), 5018-5029. http://dx.doi.org/10.1007/s11356-019-07116-4. PMid:31848961.

Zapevalov, M. V., Sergeyev, N. S., Redreev, G. V., Chetyrkin, Y. B., & Zapevalov, M. S. (2019). Technology of poultry manure utilization as a renewable energy source. *IOP Conference Series. Materials Science and Engineering*, 582(1), 012036. http://dx.doi.org/10.1088/1757-899X/582/1/012036.

Zhang, L., Li, H., Zhu, J., & Yan, J. (2020). Structure and dyeing properties of cotton fabric modified by protein from waste feathers. *IOP Conference Series. Materials Science and Engineering*, 774(1), 012043. http://dx.doi.org/10.1088/1757-899X/774/1/012043.

Zhu, G., Zhu, X., Wan, X., Fan, Q., Ma, Y., Qian, J., Liu, X., Shen, Y., & Jiang, J. (2010). Hydrolysis technology and kinetics of poultry waste to produce amino acids in subcritical water. *Journal of Analytical and Applied Pyrolysis*, 88(2), 187-191. http://dx.doi.org/10.1016/j.jaap.2010.04.005.

Zhumanova, G., Rebezov, M., Assenova, B., & Okuskhanova, E. (2018). Prospects of using poultry by-products in the technology of chopped semi-finished products. *International Journal of Engineering & Technology*, 7(3.34), 495-498. http://dx.doi.org/10.14419/ijet.v7i3.34.19367.

Zou, Y., Yang, H., Zhang, X., Xu, P., Jiang, D., Zhang, M., Xu, W., & Wang, D. (2020). Effect of ultrasound power on extraction kinetic model, and physicochemical and structural characteristics of collagen from chicken lung. *Food Production, Processing and Nutrition*, 2(1), 3. http://dx.doi.org/10.1186/s43014-019-0016-1.