Chapter 19
Current Trends and Prospects of Transforming Animal Waste into Food

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Abstract Animal waste production is a disquieting situation all over the world. Presently, research and development is working to utilize waste for producing value-added products (manure, animal feed, etc.), extraction of valuable compounds, renewable energy, and biodegradable packaging material production. This chapter discusses the extraction of protein (keratin, collagen, gelatin, myofibrillar, and blood protein) from animal waste and its application in food industries. Furthermore, this chapter also reviews bone meal and fish meal application and the utilization of animal protein in the development of packaging film. The review also discusses the regulatory status of waste material in packaging along with ethical and religious concerns and future prospects of animal waste in nutricosmetics, biotechnological, and dairy probiotic beverage development. The waste utilization in effective way will be an efficient tool to be a part in control of climate change.

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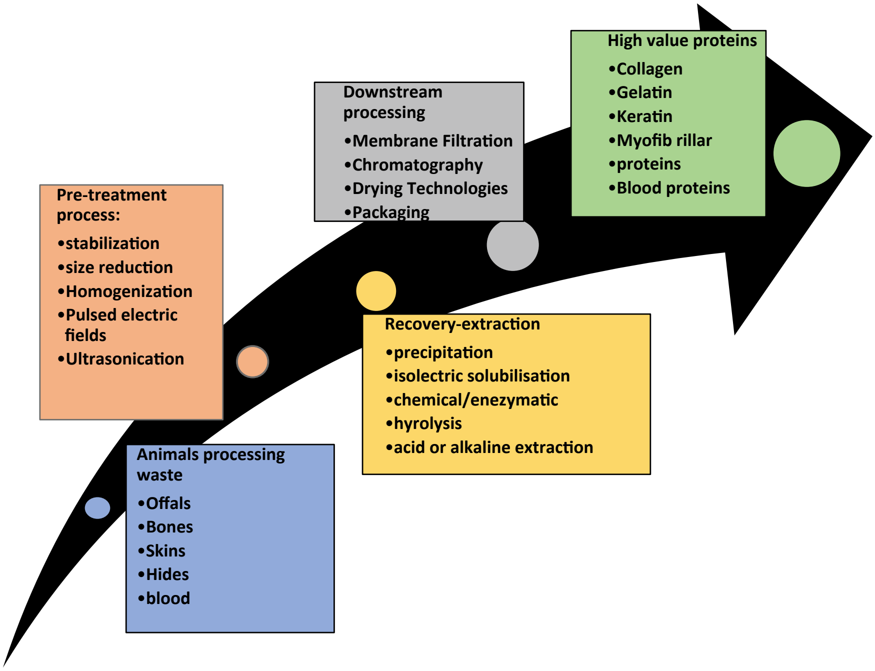
Graphical Abstract



Keywords Protein · Fish bone meal · Packaging film · Climate change

19.1 Introduction

The world population is estimated to exceed 10 billion by the end of 2050 (Duque-Acevedo et al. 2020). Around the world, different countries are trying to enhance the production of food to feed ever-growing populations in the future. As a result, the industrialization of agriculture and allied sectors would further be promoted which in turn will certainly increase the production of waste. The farm mechanization preferences and progress in industrialization have increased the production of agro-industrial waste. In general, the waste produced by agricultural fields and the agri-food industry is nutrient-rich and cannot be left untreated (Sadh et al. 2018). Globally, about 50% of the total waste produced is deposited in open dumps and landfills (Millati et al. 2019).

Managing such a large amount of waste is resource-intensive and challenging work. Interestingly, it can be utilized as a raw material for the production of value-added products, extraction of compounds for use in food, production of renewable energy, and development of biodegradable packaging materials in the present times (Birania et al. 2022).

Recognizing the importance of these agro-industrial wastes, authorities propose their transformation into value-added products (Mora et al. 2019; Álvarez et al. 2010). In advanced countries, animal products are considered as main sources of protein in the diet. Globally, 45% of overall protein consumption comes from animal sources, which is predicted to rise by 135% until 2050 (Lynch et al. 2018).

Mutton, beef, poultry, and pork are the highly consumed meat types and are commonly served as processed meats, pies, burgers, and sausages. In addition, various materials as co-products can be obtained in the production of these main products and considered as secondary products. Chitin, fat, and animal protein are the chief by-products that can be obtained from poultry, livestock, aquatic species, and domestic animals and generally account for 1/3 to 1/2 of an animal's live weight (Khodaei et al. 2021). Direct consumption of meat by-products is relatively small, majorly due to cultural and traditional practices, consumer perception, and ethical and religious restrictions. In addition, public health concerns, e.g., bovine spongiform encephalopathy can be reasons of the low consumption of these by-products. Thus, worldwide efforts are being made to reduce the dependence on animal protein and to discover a model route to utilize animal waste produced during meat processing and could be effectively utilized in pharmaceuticals, animal feed, pet food, industrial applications such as plant growth stimulators, adhesives, cosmetics, textile, water treatment, and biopolymers (Lynch et al. 2018).

The utilization of by-products in any of meat industry cannot only uplift their revenue but also shows positive impact on environmental pollution with zero waste generation (Henchion et al. 2016). This waste is also thought to be a high-quality raw material with low commercial value for the production of valuable products such as chitosan, chitin, gelatin, collagen, keratin, enzymes, peptides, oils, ω-3 fatty acids, and fishmeal (Araújo et al. 2018a).

Protein remains in these products as obtained from animals are inexpensive sources. Meat by-products and wastes from slaughterhouses or processing industries are utilized as starting materials for the production of value-added products. The major steps for protein recovery from meat processing wastes include pretreatment, extraction, and downstream processing (Khodaei et al. 2021). Figure 19.1 showing processing of animal waste.

In the past three decades, one of the biggest issues discussing worldwide is "climate change". Animal waste disposal is impacting on climate by increasing surface temperature, increasing mean sea level, and variability in rainfall. There are a lot of calls published on mitigation of climate change but not on adaptation. The current review article is proposing ways by explaining that sets up waste segregation and then recycles it. Animal waste is its offal, bones, skins, hides, and blood and fortunately, all of these contain a lot of nutrients and beneficial factors that can be extracted and converted into valuable products. It would be very challenging by 2050 to fulfill the need of food for estimated 9 billion people in the challenging time period of climate change. It is the dire need to drive efforts be on track to control the rise in temperature and to achieve sustainable development goals (Batini 2019).

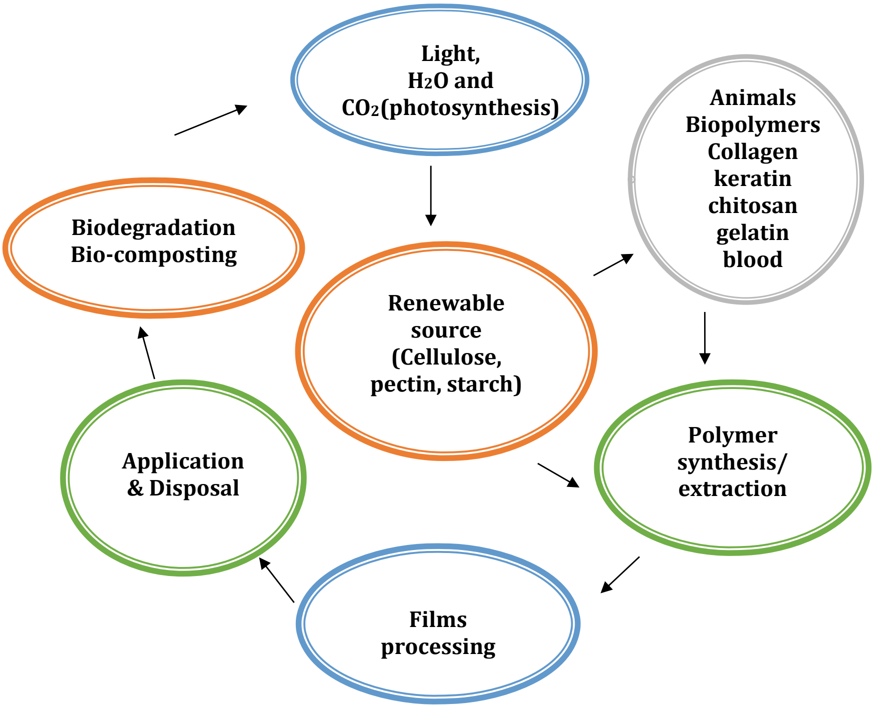


Fig. 19.1 Biodegradable polymers life cycle from natural sources (Mohanty et al. 2005)

19.2 Extraction of Protein from Animal Waste

19.2.1 Keratin Pretreatment and Extraction

Various research has been performed to isolate keratin from animal wastes in the last few years. These strategies belong to two major classes: proteolysis and protein denaturation. Based on protein denaturation, the techniques are divided into oxidative, sulfitolysis, or oxidative, whereas alkaline, enzymatic, and microbial techniques are based on protein degradation (Chilakamarry et al. 2021). Protein denaturation methods yield the highest weight keratins, but are time-consuming and use chemicals that are toxic and pollute the environment (Shavandi et al. 2017).

As keratin contains cysteine and amino acid cross linkages, its extraction using any technique either solvent or non-solvent is challenging. Methods that cause keratin denaturation include agents such as surfactants, chemicals, and hydrolytic agents that play an important part in keratin extraction by breaking sulfide bonds without affecting the keratin structure (Wang et al. 2016). First, denaturing substances and chemicals increase the ability of keratin to absorb water and swell by splitting the hydrogen and reducing the hydrophobic bonds in its structure. In the next step, sulfide bonds are broken down using chemicals that are either oxidative or reductive depending on the reaction mechanism (Kakkar et al. 2014). To improve keratin solubility in water, urea is commonly used as a denaturing agent. The effectiveness of a surfactant depends mainly on its interaction with the keratin. Anionic surfactants are reported to be more effective than cationic and neutral surfactants (Eslahi et al. 2013).

Various studies have reported sodium dodecyl sulfate (SDS) as an effective surfactant as it enhances the rate of keratin extraction through a bi-nucleophilic displacement mechanism. The process involves two reducing agents producing kerateins with thioglycolic acid and 2-mercaptoethanol as reducing agents. As the degradation of keratin takes place at pH more than 11, most of the reduction reactions are performed in alkaline conditions. For the process of reduction, mercaptoethanol is often used but it is undesirable because of its unpleasant odor and is also poisonous (Pan et al. 2016).

Peracetic acid ($C_2H_4O_3$) and performic acid (CH_2O_3) are generally used to break keratin disulfide bonds and oxidize cysteine into cysteic acid residues. Then oxidized keratin is known as keratoses that is modified chemically and can be separated at different pH and solubility into α-, β-, and γ-keratoses fractions. Another technique used to cleave sulfide bonds is sulfitolysis which uses sodium sulfite ($NaSO_3$), sodium bisulfite (NaS_2O_5), and sodium bisulfite ($NaHSO_3$) (Lee et al. 2014). To break disulfide bonds in wool, a new organ phosphonic chemical called LKS-610 was used. The chemical produces thiol groups upon interaction with disulfides and a considerable decline in cysteine content was observed (Li et al. 2019).

Alkaline extraction uses hot alkali solutions to break down amide linkages in keratin converting them into amino acids such as cysteine which is the most abundant amino acid found in keratin structure (Gupta et al. 2012). A highly concentrated basic solution can isolate hydrogen from sulfur and carboxyl groups. During this process, the decomposition of peptide chains forms alkali sulfides having an unpleasant odor. When the alkali concentration is less than 10%, there exist a direct relation between solubility of keratin and the alkali's concentration. Increasing the NaOH concentration from 15 to 38% enhances the strength of wool fibers by approximately 30%. Cysteine is among the major amino acids found in wool and is degraded in strong alkaline solutions. Process parameters must be adjusted to retain cysteine during the derivation of protein (Shah et al. 2019).

Trifluoromethanesulfonyl (1-Hydroxyethyl-3-methylimidazolium bis), as hydrophobic ionic liquid (IL), is widely used to isolate and extract keratin from chicken feathers. Investigation of the effects of IL, $NaHSO_3$ (reducing agent), temperature, and reaction time showed that keratin yield rises from 7 to 15% as the mass ratio increases (Chilakamarry et al. 2021). One of the important factors that affects keratin extraction yield is temperature. Temperature affects the yield in three different steps; (1) Increasing the temperature from 70 to 80 °C enhances the yield. (2) A rise in temperature from 80 to 90 °C had no effect on the yield. (3) An increase from 90 to 100 °C resulted in a lower yield (Ji et al. 2014).

To break down and decompose keratin into peptides, methods involving enzymes and microorganisms can also be used. The procedure used for the degradation of keratin with the help of bacteria has not been described yet. One of the microbial enzymes that breaks the bonds of keratin protein is keratinase which is produced by some microorganisms. The decomposition of keratin in the presence of microbial enzymes does not alter the structure of proteins and retains its functional properties (Chilakamarry et al. 2021; de Menezes et al. 2021).

The weight of keratin isolated by environment friendly techniques such as IL extraction, alkaline extraction, steam, and superheated water varies depending on the processing conditions. Keratin having molecular weight below 10 KDa is not suitable to be used as a structural material (Fagbemi et al. 2020). Thermal methods (superheated water, steam explosion, microwave) use steam and high pressure which destroys keratin and the yield is also less. The yield of keratin extracted using enzymes is unclear and an expensive process. More research is required to assess cost effectiveness for the process and extract keratin with similar physicochemical properties depending on the source and method (Fagbemi et al. 2020).

19.2.2 Gelatin and Collagen Extraction

The removal of non-collagen components from animal's waste is essential before collagen extraction. Various pretreatments including degreasing, swelling, and demineralization are used for this purpose. By the use of alkali treatments with sodium hydroxide (NaOH), non-collagen components are removed with the swelling of raw material. Although the concentration of NaOH and solvent temperature can be changed depending on the nature of raw material and extent of cross-linking found in collagen, the use of higher concentration for NaOH at 4–20 °C should be avoided to prevent damage in collagen structure (Zhang et al. 2013).

Demineralization of collagen is achieved with hydrochloric acid (HCl) and ethylenediaminetetraacetic acid (EDTA). EDTA, as compared to HCl at same concentration, has been reported to present better decalcification properties from animal bones and fish scales. For fat extraction, solvents such as n-hexane and ethanol are used. Pretreatment has been reported to have a significant effect on the degree of hydrolysis while collagen is being extracted from bovine animal's waste. Presently, numerous novel approaches such as high pressure processing, ultrasound, and microwave-assisted extraction are being used to facilitate pretreatment methods for isolating and extracting collagen (Chotphruethipong et al. 2019). The cavitation resulting from a high frequency ultrasound irradiation has the potential to disrupt raw material and break them into simple and small pieces thereby increasing the surface area extraction (Zou et al. 2020).

With high ultrasound frequency, the shear rate has been observed to increase with a decrease in length of bubbles showing inverse relation. Among other pretreatments, thermal techniques such as boiling and high pressure processing significantly effect the degree of hydrolysis, while collagen is being extracted from bovine animals. Boiling pretreatment generally shows better efficacy than high pressure in this regard (Hong et al. 2019).

A commonly used technique to extract collagen from animal hides is enzymatic hydrolysis. The process involves a minor chemical reaction with almost no damage and side effects to the protein's structure. The applications of pepsin as an enzymatic extraction agent have been reported in various studies. It allows breakage at the telopeptide region of the triple helix in collagen's structure producing pepsin soluble collagen (PSC). It also assists in leaching of the collagen structures increasing the extraction yields while in the solution (Jin et al. 2019).

Other enzymes being used for the extraction of collagen include trypsin, alkaline protease, lactases, and papain. Hydrolysis time, enzyme nature, concentration, and solid-to-liquid ratio affect the yield of enzymatic extraction (Grønlien et al. 2019). Following trend has been observed considering the effectiveness of enzymes for collagen extraction from bovine animals: collagenase > trypsin > pepsin (Zhang et al. 2013).

The alternative prevailing technique used for extracting collagen can be chemical electrolysis using an acid, salt, or an alkali. This one is more inexpensive and undemanding (Dhakal et al. 2018). Acid-soluble collagen (ASC) method is effective in the demineralization and extraction of collagen at low temperatures with the help of organic or inorganic acids. The extraction rates are observed to be faster with organic acids as compared to inorganic acids. Intra and intermolecular forces of the collagen helix are broken down, high molecular weight proteins are broken down into smaller units by acids such as HCl and acetic acid. The acid concentration generally varies from 0.5 to 1 M (Jafari et al. 2020). The collagen chain structure must not be affected by the acid concentration. An undesirable effect in collagen structure was seen at 1.05 M concentration of acetic acid due to side reactions. The yield of collagen extraction can also be affected by time and temperature (Blanco et al. 2019; Jafari et al. 2020). Alkaline extraction methods are less favored for collagen extraction due to poor performance, low extraction yields, and collagen denaturation (Meng et al. 2019).

Extraction methods using acids are generally an effective way for extracting collagen. But they can be influenced by various parameters such as acidity, energy consumption, and processing time thereby restricting the extraction yield resulting in an increased solubility of the final product, nutritional losses, poor function, and bitterness (Araújo et al. 2018b). The use of ultrasonic electric fields with enzyme and acidic methods can result in an increased yield, in a small amount of time. A commonly used method is combination of hydrogen bond donor and hydrogen bond acceptor called the deep eutectic solvent (DES) method (Akram and Zhang 2020; Amani et al. 2021). A supercritical fluid extraction (SFE) technique is also employed to isolate proteins using by-products. Although this method can alter the structure of the extracted protein, it is environmentally safe (Sousa et al. 2020).

Regardless of the setbacks, the acid and enzyme extraction methods are generally employed. The application of the traditional approach along with pretreatment methods improves productiveness. Although pulsed electric field (PEF), DES, SFE, and ultrasound approaches have established quite supremacy for extraction, they are more productive when combined with traditional techniques (Cao et al. 2021).

Table 19.1 is representing pretreatment and collagen extraction methods from various animal's skin.

Table 19.1 Pretreatment and collagen extraction methods from various animal's skin

Pretreatments	Collagen extraction methods and steps	References
Chicken		
Hot water bath treatment at 40 °C for 1 h	4 step extraction involving protease inhibitor solution (1 km/L NaCl and Tris-HCl 1 $\times$ 10^{-3} km L), ethylene diamine hydrochloride (24 h), acetic acid (0.5 k KM/L), and pepsin (1 g/L) followed by precipitation steps involving ammonium sulfate (25% saturation), and sodium chloride crystals	Cliche et al. (2003)
Non-collagen removal using NaOH 0.1 km/L and fat removal using butyl alcohol 10% v/v at 4 °C for 1 day	Acid hydrolysis using acetic acid 0.5 km/L at 4 °C for 42 h followed by precipitation using NaCl 2 km/L, dialysis using water and centrifugation	Du and Betti (2016)
Fat removal and de-pigmentation by centrifugation	Acid hydrolysis using acetic acid 0.5 km/L at 4 °C for 72 h followed by centrifugation and dialysis using distilled water	Jiménez Vázquez et al. (2019)
Non-collagen removal using NaOH 0.1 km/L at 4 °C for 1 day and fat removal using butyl alcohol 10% at 4 °C for 24 h	Acid hydrolysis using acetic acid 0.5 km/L for 1 day at 4 °C followed by vacuum depending on animal breed	Suurs et al. (2022)
Sheep		
Non-collagen removal using 0.1 km/L NaOH for 5–6 h at 4 °C followed by demineralization using 0.5 km/L EDTA for 48 h	Acid hydrolysis (0.5 km/L for 3 h) followed by enzyme addition (pepsin 1 g/m^3), precipitation using NaCl 2.6 km/L, centrifugation, and hydrolysis (1 km/L $NaCO_3$)	Chuaychan et al. (2015)
Washing and hair removal using deionized water	Acid enzyme treatment using acetic acid and trypsin at (0.5 km/L, 0.001 g trypsin at pH 7 for 40–60 min) followed by filtration and centrifugation	Fernandez-Hervas et al. (2007)
Goat		

(continued)

Table 19.1 (continued)

Pretreatments	Collagen extraction methods and steps	References
Non-collagen removal using NaOH 0.1 km/L for 0–48 h	Acid enzyme treatment using acetic acid 0.5 km/L and pepsin 0.1% w/v followed by precipitation using NaCl 2.6 km/L for 12 h, and centrifugation for 30 min at 4500 g	Hakim et al. (2021)
Non-collagen removal using NaOH 0.1 km/L for 1 day at 4 °C	Acidic hydrolysis using acetic acid 0.5 km/L for 24 h followed by precipitation using NaCl 2.6 km/L, centrifugation at 7000 g and dialysis using acetic acid	Wahyuningsih et al. (2018a, b)
Non-collagen removal using NaOH 0.1 km/L for 48 h at 4 °C	Acid enzyme treatment using acetic acid 0.5 km/L and 0.1% pepsin for 24 h followed by precipitation using NaCl 2.6 km/L, centrifugation at 7000 g, and dialysis using acetic acid	Wahyuningsih et al. (2018a, b)
Pig		
Degreasing through sonication using 75% sodium dodecylbenzene at 25 °C and 120 W	Acid enzyme treatment using acetic acid 0.5 km/L followed by precipitation using NaCl for 5–7 h, centrifugation at 7000 g and dialysis using acetic acid	Zhang et al. (2020)
Fat removal using ether, alkali pretreatment using NaOH 2% g/g, and sonication at 25 kHz for 40 min	Maintain alkaline pH using phosphate buffer solution followed by enzyme hydrolysis using alcalase at 1:100 w/v and centrifugation	Zhang et al. (2017)
Cattle		
Collagen was extracted from cattle skin and collagen base amalgamation for flame retardant composition was prepared and introduced into material of cellulosic textile by grafting copolymerization. Unused and raw cattle skin waste was cut into 3 to 4 mm size	Hydrolysis at alkaline pH using NaOH 3–5%, followed by filtration and neutralization using acetic acid	Nabijon et al. (2017)

(continued)

Table 19.1 (continued)

Pretreatments	Collagen extraction methods and steps	References
Salt washing using NaCl 0.5 km/L for 2 h followed by lime treatment for hair removal and non-collagen removal using NaOH 2% for 5 days	Acid enzyme treatment using acetic acid 0.5 km/L and pepsin at 1:20 w/w for 2 days followed by centrifugation at 20,000 g for 15 min, precipitation using NaCl 2 km/L for 6 h and dialysis using deionized water for 4 days	Feng and Betti (2017)
Pretreatment with hot water bath at 70 °C for 15 min	A solution of 5% calcium hydroxide and 5% acetic acid mixed with sample and hydrolyzed for 48–72 h followed by hot water bath treatment for 1 day at 70 °C and filtration	Said (2018)

19.3 Application of Animal Waste

19.3.1 Collagen as Food Additive

Substances added to food to improve the safety, texture, quality, taste, and appearance of food are known as food additives. Such substances include emulsifiers, preservatives, thickeners, and antioxidants. Collagen, a food additive, is used to enhance the rheological properties of various foods. Meat and meat products having raw materials with added collagen have better technological and rheological properties. Liverwurst or paste containing collagen has improved quality and less existence of fat caps (Hashim et al. 2015).

Heat-treated collagen fiber acts as an emulsifier in acidic products. The integrity and rheological properties of oil-in-water emulsion were evaluated. Droplet size of prepared emulsion and phase separation reduced its pH value resulting in the production of stable emulsion at acidic pH. Through high pressure homogenization, acid emulsions showed lower dispersions and six times decrease in mean surface diameter than the primary emulsions (Santana et al. 2011). Heat-treated collagen fibers are a natural alternate to man-made emulsifiers to be used in acidic foods. The heat processing in such foods decreased protein charge and solubility leading to a lowering of oil-protein interaction. Primary emulsions formed by heating collagen fiber have high creaming and emulsion rates (Aberoumand 2012).

Food-grade collagen can be used in place of lean meat in bologna. In a study, coarse bologna and bologna with fine emulsion were developed by the fibrous collagen in place of lean meat. As a result, no significant effect on shrinkage, density, stability, water content, and protein content were found. Moreover, no significant effect on color, pressure fluid, pH, or cooking loss were discovered (Kalinova et al. 2017).

Duck feet collagen was added in sardine surimi to study its effect on physiochemical properties. The added collagen resulted in improved gel hardness and strength, folding test score, and a color lightness of surimi. Furthermore, collagen proved to be an effective alternative to protein additive for improvement of surimi quality. Jelly production from the addition of chicken feet collagen also had a good response from customers (de Almeida et al. 2012; Huda et al. 2013).

19.3.2 Collagen in Beverages

Collagen-infused drinks are widely being used in the global market including various products such as soy collagen, cocoa collagen, cappuccino collagen, juice collagen, and birds nest collagen. Collagen drinks help body generate fatty tissues and stimulate the collagen making mechanism of body resulting in improved body tissues and reducing skin wrinkling and sagging (Lin et al. 2020).

Malaysian dairy industry has used collagen in their probiotic drink containing prebiotic fiber (Hashim et al. 2015). Vitagen collagen drinks facilitate the growth of healthy bacteria found in gut and also enhance skin beauty. Avon has developed "Avon Life Marine Fish Peptide Collagen Drink" which contains good quality collagen extracted from fish skin, vitamin C, and fructo-oligosaccharide. Nestle Malaysia has also launched several products including Nescafe body partner and collagen coffee containing collagen from the fish source (Binsi and Zynudheen 2019).

Collagen has a rod-like triple helix structure which is thermally unstable and plays an important role as a clarifying agent in alcoholic beverages by accumulating insoluble particles and yeast. Bovine collagen solutions could possibly be used to purify beer and yeast preparations by chemically modifying them. Collagen has a distinctive caprylic taste which can be improved by adding stevia and sucralose extract and further blending with acesulfame potassium if needed (Znamirowska et al. 2020).

19.3.3 Gelatin for Food Industry

Collagen and gelatin have wide usage as food additives and packaging materials in the food industry. Gelatin is integrated in food products to enhance their texture, color, taste, and other properties. Gelatin is majorly used as a food stabilizer and consistency enhancer as it forms stable gel and foam. It is used in water gel desserts for its melt-in-mouth property but it also forms insoluble cross-linked hydrogel that maintains its shape in swelling equilibrium (Tsykhanovska et al. 2020; Yang et al. 2020). Heat-treated collagen fiber is a natural alternative of synthetic emulsifiers. The addition of collagen in sausages improves its rheological properties and decreases fat cap of the oil-in-water emulsion. The antioxidant property of collagen hydrolysates prevents peroxidation of lipids that are dangerous for human health. This antioxidant property is linked with the radicle scavenging imidazole group of histidine (Sousa et al. 2017). To extend the shelf life of foods, collagen-based films have played a significant role. The main function of food packaging is to prevent the exchange of oxygen, moisture, and microbial activity and to maintain the sensory qualities of food material. Gelatin has been widely researched as a food packaging material because of its biodegradability, film-forming ability, and effective gas barrier quality. However, the use of gelatin has some disadvantages because of its poor strength and wide absorptive nature. It absorbs moisture in high-moisture food packaging (Fustier et al. 2015; Huang et al. 2020). A combination of gelatin with biopolymers can improve its properties by reducing mobility, improving resistance, and mechanical barrier properties. Gelatin and collagen films are used to produce sausage casings using the co-extrusion process but they are less effective due to poor mechanical properties and moisture sensitivity (Beghetto et al. 2019; Mohseni and Goli 2019). A multilayered structure can be used for this purpose containing multiple barriers to moisture and oxygen. Gelatin is the first material used as a bioactive substance carrier. Active packaging of gelatin films and coatings can be achieved by incorporating natural antioxidants and antimicrobial components. Bioactive components for active packaging could be plant extracts like rosemary, grape, lemon, and oregano. Extracts can be inactivated by heat, light, and oxygen (Benayahu et al. 2020; Regubalan et al. 2018). Researchers have tried to encapsulate solids, liquids, and gas in microcapsules to protect their functional components. Encapsulation is also a solution to control and decrease taste and smell of vegetable extracts. Gelatin encapsulation technique can be used to manufacture food formulations.

19.3.4 Keratin in Feedstock

Chemical thermal hydrolysis of chicken feathers results in feather hydrolysates that are rich in amino acids and polypeptides. They have similar composition to soybean protein and cotton seed protein used as a dietary supplement for feeding ruminants. Enzymatic-alkaline hydrolysis of feather keratin for feeding was performed (Ramakrishnan et al. 2018). Enzymatic modification through enrichment with lysine leads to an increased nutritional value. A horn meal is made by putting raw horns and hoofs under high pressure. Animal feed can be prepared by using keratin which proves as a useful protein (Brandelli et al. 2015).

19.3.5 Applications of Fish Collagen in Drug Delivery

Fish collagen has potential role in biomedical applications including wound dressing and tissue engineering techniques. However, the applications of collagen for drug delivery are limited. Recently, the researchers are gaining interest in the applications of polymeric matrices and nano and micro-particles of collagen isolated and extracted from fish for drug delivery applications (Felician et al. 2018). To study this, collagen extracted from marine sponges and jellyfish was evaluated. Fish collagen was extracted and prepared using freeze-drying technique. The extract was then incorporated with growth factors such as fibroblast growth factor in microspheres for controlled delivery. Results revealed that microspheres were dispersed uniformly into the porous structures of collagen extract and had better biocompatibility as opposed to collagen without microspheres. This allows microspheres to be used as controlled growth factors to wound site in the body (Cao et al. 2015). Table 19.2 gives protein contents and various applications of fish organs. The gels made from fish collagen extracted from skin of an eel fish were also studied for drug delivery applications. Results revealed that certain drugs including tetracycline and ampicillin were delivered effectively as the zone of inhibition appeared against different bacterial strains (Veeruraj et al. 2013). In another research, fish collagen encapsulated with negative nanoliposomes was studied for enhanced topical delivery. Results revealed that fish collagen enhanced the protein expressions of type I collagen suggesting its applications in cosmetic industries (Seo et al. 2018). Fish collagen extracted from *Lates calcarifer* scale was incorporated with *Bixa rollana* plant extract to study anticancer and antibacterial properties. Results revealed that microspheres showed consistent release of plant extract and exhibited antimicrobial properties against both, i.e., gram positive and gram negative bacteria. These studies elaborate the potential of collagen protein for the delivery of anticancer agents (Muthukumar et al. 2014).

19.3.6 Food Applications of Bone Meal

Bone meal is a combination of roughly and finely ground animal bones and waste from slaughterhouse. It is being used as a feed additive to provide monogastric animals with phosphorus (P) and calcium (Ca) in the form of hydroxyapatite. It acts as a slow organic fertilizer, and it provides plants with small amounts of calcium, nitrogen, and phosphorus.

Bone meal is utilized as a major source of phosphorus, calcium, and traces of different elements. Calcium is the basic constituent of teeth and bones. It is necessary for blood clotting, transmission of nerve impulses, muscle contraction, hormone production, and several other reasons. Stability of cell membrane is also stimulated and maintained by calcium (Coutand et al. 2008; Hendriks et al. 2002).

19.3.6.1 Dietary Supplement

Along with many other meals, bone meal, specifically meat meal, is used as a mineral/food supplement for cattle and hoofed animals. Transmissible spongiform encephalopathy, primarily known as mad cow disease in cattle, is spread by improper

Table 19.2 Protein contents and various applications of fish organs

Major organs of fish	Applications	Protein content (%)	References
Fins	Biomedical purposes, pharmaceutical, and cosmetics	17–20	Mahboob (2015)
Skin	Biomedical purposes, pharmaceutical, and cosmetics	25–28	Mahboob (2015)
Meat	Supplementation of snacks and pasta	20–22	Nawaz et al. (2019)
Egg shells	Calcium supplement and food fortification	4–8	Waheed et al. (2019)
Hairs	Antimicrobial and antioxidant	85	Pleissner et al. (2011)
Scale	Biomedical purposes, pharmaceutical, and cosmetics	22–25	Mahboob (2015)
Fish processing waste	Antimicrobial and antioxidant	11.5	Pleissner et al. (2011)
Fish processing waste	Foaming capacity, emulsifying characteristics, water retention capacity, gelling activity, and oil absorption	16–31	Ghaly et al. (2013)

use of bone and meat meal in animal nutrition. Salmonella contamination can be reduced and controlled by proper temperature control (Jiang et al. 2011).

Historically, bone meal has been used as a dietary calcium supplement for humans (Mendez and Dale 1998). Studies have shown that lead and calcium have a same atomic structure as they have in their ionic forms (Pb^{2+}, Ca^{2+}) and thus leads to the potential for lead accumulation in bones (Potera 2009). In 1970's, Allison Hayes an American actress was poisoned with a calcium supplement made from lead-rich horse bones, prompting the Environmental Protection Agency to develop stricter import regulations. In addition, in 2013, study of broth-based products of chicken bones found out that they contain more quantity of lead than present in the tap water.

19.3.6.2 Dosing Format

For bone meal, there is no Recommended Dietary Allowance (RDA). For adults aged from 19 to 50 years, the recommended daily allowance for calcium is 1000 mg/day and for women with more than 50 and men more than 70, the recommended daily dose is 1200 mg/day.

The RDA of calcium for children aged between 4 and 8 years is 1000 mg/day. The RDA of calcium for children aged between 9 and 18 years is 1300 mg/day (Atuah and Hodson 2011; Ross et al. 2011; Tangke et al. 2020).

Pregnant or breastfeeding women require some more calcium than RDA. However, it should be taken with the prime concern of healthcare provider.

19.3.6.3 Toxicity and Side Effects

In bone meal, some trace elements may be helpful. However, lead is high in bone meal. High levels of mercury may also be present there. This causes major doubts about its use as a nutritional or dietary supplement. Bone meal contains much more lead than refined calcium carbonate (Atuah and Hodson 2011).

Bovine spongiform encephalopathy (BSE) or “mad cow disease” can also be transmitted through bone meal. Bone meal and other by-products of animals that may be used as basic animal feed or supplements have been held responsible to transmit BSE. The processing procedure determines the presence of an infectious agent. There is no research or studies that claim that meal obtained from bones is suitable for human consumption (Ali et al. 2018).

There are no well-known food or drug interactions with bone meal.

19.4 Food Applications of Fish Meal

The highest quality fish meal comes from raw fish. However, to prevent oil and protein breakdown, raw fish is often handled and treated by draining, chilling (water chilling systems, mixing of ice with the fish), or chemical preservation (formaldehyde or sodium nitrite).

Fish and other seafood might be the most leading human food after cereals, providing averagely 15 percent of the global intake of protein contents. Muscles of lean fish contain 18–25% protein by weight, which is almost equivalent to poultry or beef, but contains far fewer calories. In fish, 4 to 10 cal are present in just only one gram of protein, as opposed to 10–20 cal/g of protein for lean meats. For fatty meats, caloric contents may jump up to 30 cal/g (Subhan et al. 2021).

Fish feed is the largest non-recurring operating cost in aquaculture production. Therefore, they constantly try to make food cheaper by using cheap ingredients. Therefore, they constantly try to make feed cheaper by using cheap ingredients. Fish meal is a major ingredient in several feeds and is mainly substituted due to high cost and limited global supply.

Animal feed is made from fish meal because it is rich in protein contents moreover it is also a good source of phosphorus, calcium, and other minerals. Popularity of fish meal is particularly in feed prepared for water life due to its high protein content and appropriate balance of amino acid for water life (Yilmaz and Ozmen 2020).

The raw or canned fish consists of 3 main factors: solids (dry defatted material), water, and oil. Fishmeal is made through a series of steps that include cooking, dehydration, pressing, and grinding. While cooking, at a temperature of 85–90 °C, screw press is used to press the cooked fish, which helps in the removal of liquid and "press cake" is left behind. The supernate is drained, and the remaining solid mixture is centrifuged in order to obtain "still water", from which is removed by evaporation. The pressed cake and stick water are homogenized before they enter the dryer to produce fishmeal with a moisture content of approximately 10%. During each stage of processing, different variations may arise, which will lead to obtaining fishmeal of different quality (Wood et al. 1985).

Crude protein levels, fat contents, and ash contents in good quality fish vary from 66%, 8–11%, and less than 12%, respectively. Good quality fishmeal has a crude protein level of over 66%, a fat content of about 8–12%, and ash usually less than 12%. In developing and tropical countries, sometimes "fishmeal" is processed after meat is sun-dried and milled and grind. This type of fishmeal has very high ash contents and comparatively low in protein. By-products obtained from fish that include concentration of fish protein with relatively more protein content (higher than 70%) (Watanabe et al. 2001).

In 1980s, fish silage which was acid-preserved was heavily promoted as a means of preserving raw or trash fish and for making aquaculture feed by mixing such silage with other feeds, although this practice is not extensively used (Watanabe et al. 2001).

Fish meal, roughly grinded powder from flesh of cooked fish. Although previously important as fertilizer, now fishmeal is used mainly for animal feed, particularly for poultry, pigs, pets, and farmed fish. Certain types of fatty fish, such as anchovies, menhaden, sardines, and herring are a major source of fishmeal and its byproduct like fish oil (Wood et al. 1985).

For processing into meal, sliced fish passes through long cookers of steam on a screw conveyor. Oil and water are than removed by pressing the cooked flesh of fish (that spoils rapidly during storage conditions). Hot air is used to dry the pressed fish cake, resulting in food with a high content of vitamin B12 and up to 50% of protein contents.

Roe, might be female fish eggs mass (hard roe), or sperm of male fish, i.e., mass or milk (soft roe), which are thought to be food. Eggs of different fish are consumed as edible food, after it is salted or smoked. Hard sturgeon eggs, from which caviar is made, is most valued. When preparing caviar, the egg mass of freshly caught fish is removed and passed through a very fine sieve, hence, separation of the eggs takes place. Moreover, cleaning the eggs from external pieces of fat and tissue. Then, salt is added to make them preserve and enhance the flavor. Smoked cod roe is eaten frequently in Scandinavia and Great Britain. Salted carp, cod roe, or mullet are the basis of taramasalata which is a Greek appetizer (Bledsoe et al. 2003).

Soft caviar can be fried or poached and is sometimes served as an appetizer or light first course. Other roes' fish that are particularly well eaten are mackerel, herring, sole roe, salmon, and shad.

Scrod is a young fish, particularly fish is cut up and boned for smoking or cooking. The origin is believed to come from an Old Dutch word that means "to grind". In around 1841, it seemed to be used for the first time (Shenderyuk and Bykowski 2020).

Sashimi, a specialty of Japanese main course food, where raw fresh fish is served. The fish should be absolutely fresh and is cut into very thin slices or quarter to about half an inch (0.75–1.5 cm) thick slices, cubes, or strips, depending on the nature and type of the fish. Wasabi and soy sauce are added to the sashimi. Japanese meal must contain Sashimi as a food starter, served before food, while the flavor is still clear so that its nuances can be adopted.

The commonly used fishes are harvested from oceans: yellowtail, tuna, sea bream, flounder, and mackerel. Fish harvested from freshwater includes carp and perch. They can also be eaten as raw, as are prawns, abalone, clams, and lobsters. With sashimi, sake is traditionally taken in its liquid state (Cozzo and Smart 2020).

Kippers, a most traditional and common British breakfast dish, consisting of herring aged by kippering-cut, gutted, cleaned, salted, and then smoked. It may be sautéed, fried or grilled.

The best quality kippers possess pale copper color and harvested from the Isle of Man, Scotland, and northern England. Kipper is often served with lemon and butter but sometimes with a poached egg. The dish may be sometimes served at dinner or with tea (Alfian et al. 2020).

Fish sauce, in Southeast Asian cooking, a liquid condiment made by fermenting saltwater or freshwater fish with salt in large quantities. After several months, the resulting brown liquid, which might be rich in proteins, is drained and bottled. Sometimes, it is provided with stay time to mature in glass in the presence of sunlight or bottles made of clay before its use. Worldwide, it is recognized with different names like nuoc am in Vietnam, in Thailand, it is known as nam pla, in Cambodia, it is known tuk trey, patis in the Philippines, ketjap ikan in Indonesia, and ngan-pya-ye in Myanmar. Fish sauce is widely utilized as soy sauce in regions like Vietnam and Thailand. Oyster sauce made by Chinese chefs has a similar preparation method that is being used particularly in Cantonese dishes (Choksawangkarn et al. 2018).

Fish oil, a fatty oil extracted from the fish body, that is used in the production of several different products such as cooking oil, margarine, soaps, sealants, cosmetics, paints, candles, lubricants, industrial coatings, and water repellents. Fish oil is also extensively used in leather tanning, rubber production, and the production of various chemicals used to make synthetic wax. Sardines, herring, and menhaden are the main sources of fish oil. During the production of fishmeal, oil and water are squeezed out of cooked fish and separated by a centrifuge. Before storage, the oil is additionally purified by a centrifuge. Fish oil is rich in unsaturated lipids. Oil extracted from fish liver was once considered to be a major source of vitamins A and D. These vitamins are now being synthetically produced at relatively cheaper prices (Sidhu 2003). Table 19.3 shows the protien extraction from fish waste and applications in food.

Table 19.3 Protein extraction from fish waste and its application in food

Source	Protein	Application	References
Skin of sucker catfish (*Pterygoplichthys pardalis*)	Type I collagen	Fresh cheese	Nurubhasha et al. (2019)
Grass carp collagen (GCC) films	Collagen	Pork preservation	Ameer et al. (2020)
Alaska pollock (*Gadus chalcogrammus*) and the pacific cod (*Gadus macrocephalus*), waste from fish cutting (heads, swim bladders, fins, skin, and bones)	Gelatin > 80% protein	Fish culinary products	Zarubin et al. (2021)
Several fish species	Fish protein hydrolysates (FPHs)	Alternative for synthetic antioxidants rich source of bioactive peptides	Desai et al. (2022)
Fish skin and cartilage tissue of salmon fish and fileting waste (heads, fins, vertebral bones) of cartilaginous fish species	Protein hydrolysates characterized by a high protein content (up to 80.0%)	Biologically active food additives, multicomponent food system	Zarubin et al. (2020)
Pepsin-solubilized collagens (PSC)	Type I collagen	The resulting PSC from the five tissues would all be potentially useful commercially	Liu et al. (2012)
Swim bladders of *Catla catla* (Catla)	Gelatin	Flow properties of gelatin revealed non-Newtonian and pseudoplastic behavior	Chandra and Shamasundar (2015)
Nile tilapia (*Oreochromis niloticus*)	Fish protein hydrolysate (FPH)	Diets for carnivorous and omnivorous shrimp	Silva et al. (2014)

19.5 Application of Animal Wastes in Food Packaging

In recent decades, the demand for packaging materials has also increased with the growth of the food industry. The conventional petroleum-based plastics are not biodegradable and pose serious environmental problems, such as threats to marine life including plants and animals and causes environmental pollution with deterioration of quality of air (Zhong et al. 2020). In addition, burning results in the release of toxic gases (carbon dioxide, carbon monoxide, chlorine, 1,3-butadiene, furans, amines, dioxins, etc.), reducing air quality, increasing the threat of global warming, and contributing to many health concerns. The waste may contain such substances that are non-degradable and it negatively impact on environmental and health of human being, have fueled worldwide interest in finding environment friendly alternatives (Luckachan and Pillai 2011; Shaikh et al. 2021).

In contrast, biodegradable material in waste in non-synthetic contains no toxic effect and can be easily degraded due to its environment friendly polymers that have capacity to breakdown in home and industrial composting condition. These biodegradable polymers could be the outcome of natural resources or from by-products and wastes of agricultural and animal processing. Animal processing by-products are low-value and underutilized non-meat materials that are generally produced from meat processing or slaughterhouses, such as skin, blood, and viscera. There is a long list of biopolymers produced from animal waste but the most highlighted in value addition are gelatin, collagen, keratin, myofibrillar protein, and chitosan. They have many uses in the food and pharmaceutical industries, but a significant amount is underutilized and could potentially be used to produce bio-plastics. This section summarizes research progress on the use of meat processing by-products to produce biodegradable polymers with a focus on food industry applications. Additionally, current industry status and regulations for utilization of biodegradable are also discussed. The plastic material is the major concern of environmental pollution and in ocean is about 100–200 million tons of plastic waste, and it is estimated that 8 million tons of plastic are dumped off every year (Kurtela et al. 2019).

Figure 19.1 shows life cycle for biodegradable polymers from natural source. Different food categories have separate storage and transportation conditions, e.g., fruits and vegetables preservation requires a slow rate of respiration and transpiration, which usually depends on equilibrium relative humidity, temperature, light and gas (O_2, CO_2, and ethylene). Dairy products such as milk, cheese, and cream must be protected from oxidation and microbial growth, so extrinsic factors including oxygen, light, and humidity must be carefully considered. Meat products transportation showed discoloration, which can be avoided by vacuum packaging or controlled atmosphere. Eco-friendly biopolymer packaging is widely used to ensure the safety and quality of meat products (Chen et al. 2019).

19.5.1 Biodegradable Packaging Materials

Packaging materials that are usually biodegradable are derived from natural resources that are sustainable or food or by-products of agricultural (Fig. 19.2). Studies have shown that animal proteins are highly nutritious and have techno functional properties such as gelling properties, emulsification, water, and oil holding capacity (Pérez-Andrés et al. 2019). These proteins are natural, inexpensive, and abundant, and their remarkable functional properties may make them excellent candidates for the production of biodegradable films. In addition, protein films are fully compostable and provide a source of nitrogen, thus exerting a fertilizing effect during decomposition

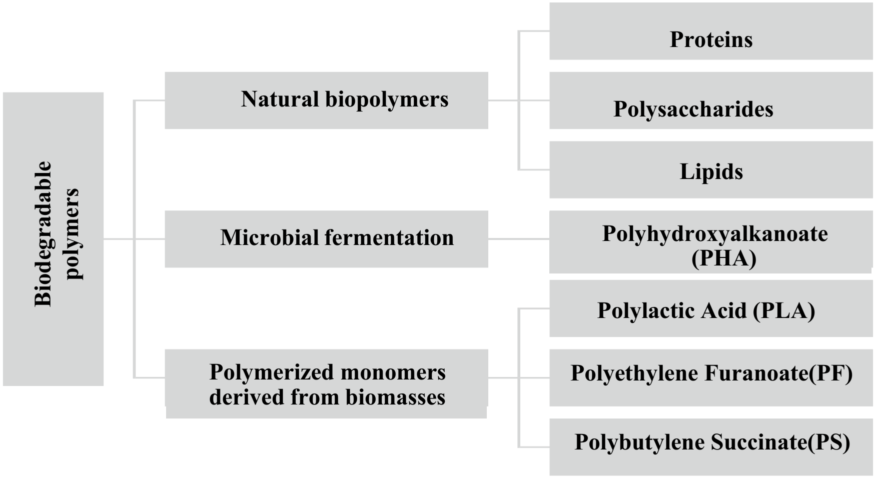


Fig. 19.2 Biodegradable polymers from different sources

in the soil. The biodegradable films are usually produced from proteins (gelatin, collagen, etc.) obtained from animal waste (da Rocha et al. 2014).

19.5.2 Development of Packaging Films from Animals' Proteins

19.5.2.1 Collagen Films

The skin, bones, ligaments, tendons and cartilage of pigs, cattle, and aquatic animals' are rich source of collagen. Their skin and peel have 30–35% protein. The collagen is fibrous protein that give structural support to different organs of body and ensure the strength and flexibility required for effective movement, tissue regeneration, and repair via processes of mechanical and chemical conversion (Sorushanova et al. 2019). Collagen is generally colorless and opaque and exhibits remarkable viscoelastic properties with high tensile strength and low elongation (Avila Rodríguez et al. 2018).

19.5.2.2 Gelatin Films

Gelatin is a water-insoluble protein produced from moderate hydrolysis of collagen (by chemical, enzymatic, or thermal methods). The type of collagen, the source, and the age of the animal are important factors that affect the properties of gelatin of particular interest are, fish skin, bones, scales, cooked filets, solid waste from surimi processing, offal from processed or semi-processed fish products, farmed alligator bones, and giant Red Sea cucumbers are examples of potential marine by-products. It can be used as a source of collagen and gelatin (Gómez-Guillén et al. 2011).

Studies have shown that gelatin films are suitable for food packaging applications due to their high mechanical strength, transparency, and barrier properties (Khodaei et al. 2020). However, the mechanical and inhibitory properties of gelatin films strongly depend on the amino acid composition and molecular weight of the polymer. Different amino acid compositions and processing conditions between species affect the molecular weight distribution of gelatin. According to the US Food and Drug Administration (FDA), EC, FAO and WHO, gelatin is a safe additive for food industry applications and can be widely used in biodegradable or especially edible packaging. Due to high hygrometry, gelatin layers in contact with food and surfaces containing high amounts of moisture show high swelling and dissolution capacity. A microbial transglutaminase, widely used to enhance the mechanical and inhibitory properties of gelatin or protein films, has also been approved as a generally recognized as safe (GRAS) substance by the FDA since 1998.

19.5.3 Keratin Films

It is a structural protein of horns, wool, hoofs, hair, nails, etc., and insoluble in nature. The keratin and creatine proteins exhibit mutual resemblance with each other to perform the functions. The creatine proteins are rich in cysteine (sulfur-containing amino acids) which link the surrounding cysteine residues through intermolecular and intramolecular interactions to build disulfide and hydrogen bridges. These bonds give keratin a crystalline structure, high stiffness, and elasticity potential (Barone and Arikan 2007). It is noticed that 65 million tons of feathers and 2.5 million tons of wool are globally produced every year. In this production, 1.5 million tons of wool is used for low/small value and in textile industry and other part is burnt and employed for landfilling (Shavandi et al. 2017). Various researchers reported that keratin films on mixing with glycerol give clearer films with pronounced mechanical strength (Yin et al. 2013). Although these films are generally very weak but can be used as humidity sensors for rough surfaces being cost effective and porous in nature (Hamouche et al. 2018).

19.5.4 Myofibrillar Proteins

These muscular proteins, on the basis of their solubility in water and location in skeletal muscle are divided into sarcoplasmic, interstitial, and myofibrillar. These form 60% of muscle proteins as the main component and responsible to perform remarkable functions of emulsification, gelling properties, and solubility (Dong et al. 2020).

The research has been conducted to study the effect of processing conditions on muscular proteins derived from fish waste. Later on, these proteins were used in film production to observe its characteristics. It was noticed that the produced films exhibit the uniform structure, low water vapor permeability, good mechanical properties, making it suitable for food packaging materials due to its 35.96% softener, drying temperature of 25.96 °C, and 1.13% protein content. Another study investigated the effects of various fatty acids (palmitic acid, caproic acid, and stearic acid), including surfactant (sodium lauryl sulfate) on the physical properties of fish filet-derived muscular (myofibrillar) proteins As a result, it was found that the addition of surfactants and fatty acids significantly improves the elongation and flexibility of the film and also increases the soluble rate of the prepared film (da Silva Pereira et al. 2019).

19.5.5 Blood Proteins

It is an excellent source of heme iron and essential amino acids and considered as one of the main protein-rich by-products of the meat industry. In present era, blood after collection from animal slaughterhouses is being used in pet food production, biogas production, biotechnology, and biofertilizers manufacturing industries with its less amounts for food applications. The physical properties of the prepared films of blood were studied by several authors at varying concentration of glycerol and plasma protein concentrations. The researcher Nuthong and their team (2009) (Nuthong et al. 2009) prepared films from plasma of pig in first attempt. During study, it was noticed that glycerol decreased the moisture resistance while increasing the transparency and elasticity of the films. It was also observed that the relatively high solubility of blood-based films limit their usage in food applications. The same authors conducted the another study by using glyoxal and caffeic acid as cross-linking agents in order to reduce the solubility of porcine bases plasma membranes in aqueous solutions. The findings were that the use of glyoxal in food is limited due to its toxic effects, while caffeic acid has a negative effect on the appearance of the films. The effects of mixing of chitosan and porcine plasma proteins at different levels were investigated by Samsalee and Sothornvit (2020) in another study. The addition of chitosan increased the mechanical properties and thermal stability while decreasing the water solubility, water vapor permeability, and transparency of the blend films. The same scientists reported that heating of porcine plasma protein solution followed by homogenization tends to improve the seal and mechanical strength of the plasma layer. Furthermore, the mechanical properties and water resistance of the resulting films could be improved by incorporation of microencapsulated turmeric oil or chitosan. These active package help to increase the storage life of packaged rice grains up to 50 days in comparison with untreated plasma-based protein films (40 days) (Samsalee and Sothornvit 2020). Development of biodegradable films from animal waste has been shown in Table 19.4.

Table 19.4 Biodegradable packaging films developed from animal wastes

S. No.	Source	Extraction method	Results	References
1	Fish skin	Acidic extraction	The thickness and elastic behavior of gelatin film were increased by adding palm oil and clove oil can enhance antimicrobial property	e Silva et al. (2021)
2	Chicken Skin	Alkali extraction with NaOH	The rice flour in films enhances water vapor pressure and thermal properties of films and decreases solubility, UV, and light transmission. Blended films with 20% rice flour gave best result	Soo and Sarbon (2018)
3	Bovine bones	Acid treatment	Addition of microbial transglutaminase enhances the molecular weight, stability of network structure, and mechanical strength, and the resultant films were insoluble in water	Ma et al. (2020)
4	Chicken feathers	Alkaline hydrolysis	Keratin from feathers of chicken in biodegradable films showed a tensile strength of 3.62 MPa and Young's Modulus of 1.52 MPa, and elongation at break was 15.8% that proved its suitability for bioplastic films	Liu et al. (2018)
5	Sheep wool keratin	Alkaline mild oxidative method	Keratin from wool of sheep showed increase in transparency, thermal stability, and UV barrier strength	Fernández-d'Arlas (2019)

(continued)

Table 19.4 (continued)

S. No.	Source	Extraction method	Results	References
6	Goat hoof	Soxhlet apparatus	Blood fibrin, keratin, gelatin, mupirocin used in biodegradable films of wound healing. The study showed cell viability, biocompatibility, cell adhesion, and proliferation of blended polymers	Sellappan et al. (2022)

19.5.6 Regulatory Status for Animal Waste Based Packaging Material

The European Union (EU) has developed regulatory policies since the 1970s on the quality control and analysis of food packaging materials to regulate both commercial reasons and consumer health. The Food and Drug Administration (FDA) defined food packaging/contact materials to ensure safety of food under the intended usage conditions. Migration testing must be prerequisite to demonstrate that the packaging material should be safe for use in agricultural product packaging and not transfer toxic substances to the product. According to the EN 17033 standard of European Union, these materials must use as edible films or coatings for food should exhibit GRAS status, with the exception of an allergen and it must be indicated on the label In addition to these, biodegradable mulch films used in horticulture and agriculture made of thermoplastic materials must degrade at least 90% for 48 months at 25 °C (Nieto 2009).Conclusively, petroleum-based plastics are the predominantly used polymers in the food packaging sector over the past decades, and this increased production has raised concerns about environmental contamination. However, innovations for increasing annual production and demand for biodegradable packaging materials in the food and agriculture sector lead to the pronounced production and processing of animal-derived products. These tools, to produce the non-petroleum biodegradable plastics from co-products or even waste, can provide more sustainable solutions to support the concepts of circular bio-economy, and also helpful to optimize the use of natural resources.

19.6 Religious and Ethical Concerns Related to Food Application of Animal Wastes

19.6.1 Religious Concerns

Despite the immense efforts to maximally utilize animal wastes in food sector, consumer has religious and ethical concerns in terms of religious prohibitions, safety of these waste products, and fraudulent usage of these products in food. Although scientific data have shown some of these concerns are meaningless and have not ground. However, concerns and anxiety expressed by the consumer are real and warrant a serious effort by government, researchers, and food manufacturers to diminish these fears and so ensure the sustainable utilization of these products.

Religion is associated with morality, deity, one's worldview of daily life. A person must strictly adhere to religion in relation to anything which he consumes. Animal waste could be a source of valuable bioactive compounds but in many regions of world it is regarded as dirty, dangerous, and disgusted. Halal is a concept that defines anything to be allowed according to the Islamic laws commonly employed with all kind of food products and food ingredients and food contact materials (Herpandi et al. 2011). Halal must cover the whole process beginning from the selection of source material, preparation, storage, handling, transportation, and distribution till consumption point. According to an estimate, there will be more than 31% of Muslims worldwide and to fulfill the consumption needs provision of halal food sources is essential (Hackett et al. 2017). Therefore, there is great need of halal food source authentication due to the strict adherence to religious obligation of consuming halal only. Gelatin and gelatin-based products are considered as mashbooh/doubtful because porcine (haram) gelatin is most abundant so traceability of gelatin is important to safeguard consumer from food frauds and to protect the consumer health. In Europe, around 80% gelatin is produced from pig (haram source) and used further in food manufacturing operations. In majority, slaughtering is not performed according to the Islamic laws which make the product or process overall haram. Halal products are also gaining popularity because of consumer awareness that these products are healthier, safe, and obtained by using humane animal treatments. Thus, due to the growing concerns among consumers, the halal industry is also on rise. Islam forbids dogs, donkeys, while Jews also have a law called kosher. Buddhist and Hinduism are destined to eat vegetables or not to eat cattle. Waste products obtained after slaughtering such as animal hides, cattle and poultry skins, bone, and fish meal are processed further to obtain secondary products such as keratin, gelatin, collagen find application in food industries in manufacturing operations. The halal status of these secondary material depends upon the nature of raw material or practices used. Muslims and Jews do not consume hides, skin, and blood of animals because of religious dictates enshrined in Halal and kosher dietary laws. Quran also explains that Muslims should eat halal or good food, therefore, halal status of food is a major concern for Muslims;

> O Muhammad! Tell them; "I do not find in what has been revealed to me anything forbidden for anyone who wants to eat unless it is carrion, outpoured blood and the flesh of swine, all of which is unclean; or that which is profane having been slaughtered in a name other than that of Allah. But whosoever is constrained to it by necessity, neither desiring to disobey nor exceeding the limit of necessity - your Lord is surely All-Forgiving, All-Compassionate". (Al -An‛Am:145).

19.6.2 Ethical Concerns

Animal-based secondary food products contain an abundant quantity of proteins with vitamins, minerals, and essential amino acids. The fraudulent usage of these products for economic gains is a significant concern. Partial replacement and adulteration with prohibited ingredients offer a major economic incentive to manufacturer by misleading the consumer. Inconsistency in legislations, misleading labeling leads consumers to doubt the quality of these products. Efforts to ensure the usage of these products are not abused at manufacture level as however the issue has not yet properly addressed.

Vegan community consumes only plant-based diet and avoid consuming animal-based products for ethical reasons. Therefore, it is imperative to adhere strictly with labeling laws compelling food manufacturers to clearly elaborate the usage of these products on label in layman's language to help individuals of such community to select for right food choices. Furthermore, technical labeling is not helpful and needs to be revised declaring the source of food ingredient must be deemed necessary not voluntary.

The belief that animal waste products is highly loaded with pathogenic microflora and toxic residues is another reason people are against utilization of these ingredients in food. The concern is almost genuine as these products get easily contaminated with spoilage microflora through poor processing operations or if inherent the situation can worsen. FDA in 2005, proposed the usage of cattle spinal cord and brains, from those cattle not inspected or not passed for human consumption prohibited to be used in food or feed ingredient to control the spread of Bovine Spongiform Encephalopathy (BSE) (Alao et al. 2017). Animal intestines can be used as food but these are loaded with microorganisms when separated so must be cleaned and boiled before use. In contrast to edible food portion obtained from animals, consumer does not appreciate the animal waste products in disparity. Transglutaminase may improve the texture of secondary products but may create such chemical linkages which make food product indigestible or a threat to health of consumer. Other concerns include danger of consuming untested products, disgust toward animal waste product ("Yuck factor"). The societal challenges surrounding animal waste products are mainly framed primarily in ethical and consumer acceptance, therefore, need is to address genuine concerns and barriers. Existing research data on attitude and acceptability of animal waste derived food products ranging from highly hostile to highly supportive, but limited research in this perspective shows it a source of disagreement.

19.7 Future Prospects

In past few years, global population rise exhibited trends of exponential escalation (Li et al. 2019). In order to meet the ever-increasing demands of food commodities, need of the hour is to scale up the utilization of wastes into sustainable food sources (Kumar et al. 2022). Animal waste can be of good use in this regard to owing to their nutrient-rich composition. In order to safely convert animal wastes into eatables, development novel techniques is the primary task of modern developmental science (Kumar et al. 2022). Protein wastes of animal origin are the future to reduce global malnutrition issues (Colgrave et al. 2021) like Kwashiorkor, marasmus, or marasmic-kwashiorkor (protein energy malnutrition) (Leij-Halfwerk et al. 2019). In addition to it, collagen and keratin isolates of animal waste have inexhaustible biotechnological applications (Timorshina et al. 2022). Due to fibrillar structure, these isolates can be bioengineered in to multiple formats and forms to generate target drug delivery systems, nanoparticles, biodegradable food packaging material, hydrogels, and scaffold regenerative medicine (Varghese et al. 2020).

In food processing industry, animal protein isolates like collagen can be utilized in its native form as collagen biomaterial (food packaging material) and as food additive (Tian et al. 2022). Edible bio-coatings for food commodities like sausages prepared using protein isolates can retain both moisture and oxygen thus preventing lipid oxidation, which ultimately leads to preservation of organoleptic characteristics of stored food (Titov et al. 2020). Keratin-based bioplastic is thermostables and strong moisture resistant making them a suitable material to create food packaging material which can provide an additional protective barrier to food against ultraviolet radiations (Ramakrishnan et al. 2018). Fish oil is highly nutritious but unstable under environmental extremities (Gammone et al. 2018). In order to shield this rich nutritional supplement against the deteriorative impact of ultraviolet radiation, (Tokarczyk et al. 2021) must be kept in safe conditions. Due to emulsifying properties of low molecular weight keratin, it enhances encapsulation stability of fish oil (Mishra et al. 2021).

Similarly, collagen can be isolated from other animal wastes likes eggshells which have higher biosafety with low incidence of allergic and autoimmune reactions which can be used to develop dietary supplements (Xiao et al. 2021). These supplements will support development and upholding of body tissues, skin, hair, and nail tissues particularly in old age people (Senadheera et al. 2020). Development of nutricosmetics is the future use of collagen isolates from animal bones, hides and feathers which can be used to create functional foods like high protein baked crackers (Khodaei et al, 2020; Halim 2021). Similarly, Malaysia Dairy Industry is working on development of nutritious probiotic drinks with added collagen peptides to improve digestion. These peptide collagen drinks can be a revolutionary natural high-quality peptides and fructo-oligosaccharides, thus, improving global nutritional status (Hashim et al. 2015).

19.8 Conclusion

Isolated compounds from animal wastes have been found to have crucial application in food and beverage processing industry. Among them, protein isolates like collagen and keratin are of key significance to their diverse applications as protein dietary supplements, food product coatings, meat processing carriers, edible films, and food additives. Still there one certain safety concerns associated with animal waste utilization in direct food applications, as these wastes harbor potential pathogens, antibiotic resistant bacteria, and other chemical toxins which require advance and specialized procedures for eradication prior food application. Similarly, animal waste pathogen, like swine hepatitis virus, *Cryptosporidium parvum*, and *Salmonella* spp. pose potential risk to human health.

There are certain concerns raised by various religious societies and practitioners regarding application of animal wastes, particularly blood in food intended for human consumption. Although, blood can be used as nutritional additive, pharmaceutical, emulsifier, clarifier, and stabilizer. Although, blood application can be a significant contributor in food value addition but in religion like Islam human consumption of blood is strictly prohibited due spongiform encephalopathy transmission. Animal wastes can be used in food products but require advanced levels of pretreatment to ensure safety and maximum nutritional outputs for consumers.

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