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Review

Application and Future Perspectives of Keratin Protein Extracted from Waste Chicken Feather: A Review

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Abstract: In the present review, we focus on the utilization of keratin from poultry biomass. Keratin is a tough, fibrous protein that is predominantly found in various biological materials. Millions of tonnes of keratin-containing biomass are produced annually by the food sector, particularly the meat industry, slaughterhouses, and wool processing. These keratin byproducts contain 15-18% nitrogen, 2-5% sulfur, 1.20% fat, and 90% protein. Keratin extraction represents an eco-friendly and economical method for producing both uniaxially and randomly oriented polymeric products. The extracted protein can be chemically and mechanically processed to create diverse cosmetic products (lotions, shampoos, hair conditioners) and biomedical materials. Naturally derived keratin is particularly suitable for human hair and skin applications. This study comprehensively examines various keratin sources, purification methods, and separation techniques from organic waste, along with their industrial applications and future prospects.

***Keywords*:** poultry biomass, keratin, purification, cosmetics, biomedical application

1. Introduction

Keratin biomaterials have been in use for decennium, yet they are apparently new to the field. Keratin is a global class of biological material, which represents the most common proteins in the bodies of mammals, birds and reptiles. It gives the body strength and is a structural component of wool, nails, horns and feathers.[1] In higher animals it is primarily found in the epithelial cells.[2] Food industries, in the particular meat market, slaughterhouse and wool industries produces a million of tonnes of biomass containing keratin are produced each year by the food industry, particularly the meat, wool and slaughterhouse industries. More than 40 million tonnes are produced annually by the top producers, which includes the USA, Brazil and China.[3] The most prevalent keratin waste product worldwide is chicken feathers, which are produced in large quantities in poultry slaughterhouses. This organic waste can be used as a natural source for keratin extraction and utilization in industry. The intermediate filaments (IFs), a component of the cytoskeleton with a diameter of 8-10 nm, are connected with cysteine-rich proteins known as keratins.[4] Keratin and keratinous materials are subdivided into two different classes of secondary structures of proteins: α-keratin and β-keratin.[3-5] Soft tissues including hair, skin and wool from sheep are rich in keratins. These were lower in hydroxyproline and proline amino acids and higher in cysteine. However, alpha keratin can be found in the hard tissue protein of other species like nails, fish scales and bird feathers. The majority of organic solvents cannot be dissolved in keratin due to their excellent thermal stability.[5]

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Keratin was vulnerable to hydrolytic and oxidative processes because cysteine was present in sufficient amounts.[6]

A significant proportion of keratin by-products are discarded nowadays, posing a risk to the environment. Keratin wastes are divided into three groups. Despite being unfit for consumption, it does not spread illnesses to people or other animals.[7] Due to its significant cross-linking with disulfide bonds, hydrophobic interaction and hydrogen bonds form in the solid biomass. There have been various attempts in recent years to extract keratin using mechanical, enzymatic and chemical processes.[8] Chemical assist in making the occurrence and structure of keratin Hair, Wool, Nails, Claws, Hooves, Scales, Horns, Beaks and Feathers are all mostly made of keratin. The distinctive property of keratin that sets it apart from other structural proteins like collagen and elastin is its high cysteine concentration. Cysteine, glycine, proline, serine and a small amount of lysine and methionine are the major amino acids found in the keratin.[9] Some studies divided keratin into soft and hard forms according to the amount of sulphur in each. The outer layer of the epidermis and the hair core both include soft keratin, which is less resistant to other chemicals and has less cross-linking.[10] Hard keratin is a type of keratin that can be found in avian or reptilian tissues as well as in the horns, hairs and nail of mammals.[11] Keratin is an insoluble protein that is found in abundance in the epidermis outer layer and promotes the prevention of fluid loss.[12] The word keratin first appeared in the literature around 1850, to describe how keratin is formed up of hard tissues. Keratin is the most complicated protein found in vertebrate epithelial cells.[13] After cellulose and chitin, keratin protein is the third most prevalent polymer in the environment.[14] Keratin proteins are separated into two types based on their sulphur content a) soft keratin which includes skin and calluses and b) hard keratin which includes feather, hair and hoofs.[15] Keratin's high molecular weight diverse architecture leads to their long life because of disulfide bonds, hydrogen bonds and hydrophobic interaction. Keratin protein is difficult to process by pepsin, trypsin and papain.[16]

In this review article, we briefly describe the keratin function, sources, various disposal strategies, hydrolysis, different extraction methods and industrial applications: future perspectives and conclusions are discussed.

1.1 *Keratin biomaterials: A brief history*

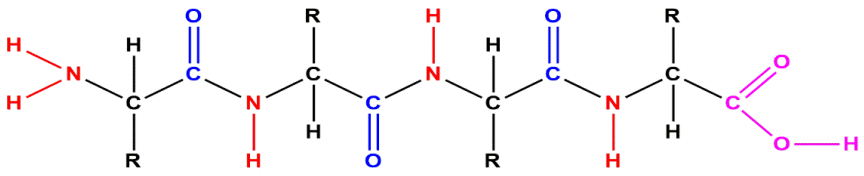
Around 1850, the word "keratin" was first used in literature to describe the material made up of hard tissues like animal horns (Keratin comes from the Greek word "kera" which means "horn") and hooves. Keratin fascinated scientists at the time because it behaved differently than other proteins. Normal methods of dissolving proteins, in particular, were effective in solubilizing keratin. Despite the fact that processes such as burning and grinding had been known for some time many scientists and inventors were more interested in possibilities. Hair and horns are being dissolved in order to manufacture better products.[17] From 1970 to the present, keratin research has been conducted the exponential expansion of keratin material and its derivatives has been supposed by advances in extraction, purification and characterization of keratin. Several research groups developed and published ways to turn isolated keratin into powder, film, gels, coating fibers and foams in the 1970s. All these approaches relied on the oxidative and reductive chemistries that had been developed decades before on the modification of them it was clear that keratin may be used as biomaterials in medical applications. A lot of scientists began to investigate the potential usage of keratin in various applications.[18]

2. Classification & sources of keratin

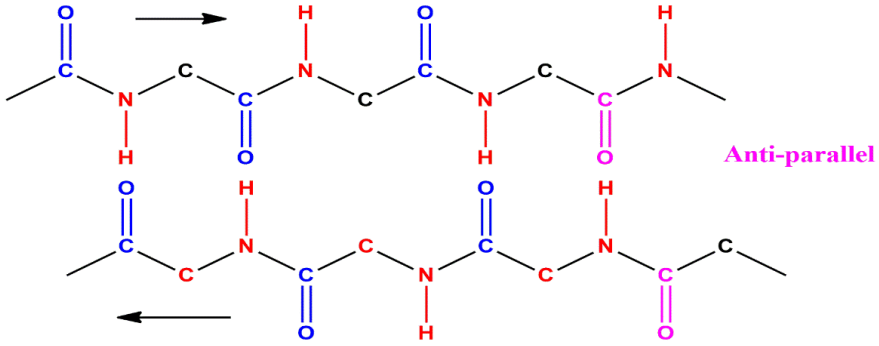
Keratin is divided into two types:

a) Alpha keratin (α-keratin) all vertebrates have alpha keratin in their epithelia because of its resistance to microbial breakdown the helix in alpha keratin is a hazard to the environment.[19] The strength, elasticity, toughness, insolubility and flexibility of the α-keratin structure shown in Figure 1a, in particular, are exceptional. Hydrophobic amino acids such as methionine, phenylalanine, valine, isoleucine and alanine are prevalent in (α) keratin.[20] This protein is divided into hard or soft keratin based on its sulphur concentration.

b) Beta keratin (β-keratin) reptiles and birds both have β-keratin as structural proteins are shown in Figure 1b. β-keratin contains a high amount of cysteine, which quickly forms disulfide bonds conferring stiffness and increasing resistance to degradation. About 80-90% of keratin is present in a mature feather individual keratin proteins normally have a molecular weight of 10-14 kDa.[21]



(a) α-Keratin



(b) β-Keratin

Figure 1. Molecular structure of Natural protein (Keratin): (a) α-keratin & (b) β-keratin

3. Major sources of keratin

Keratin is a protein that comes from living organisms or their body components after they have died. Feather, wool, hair, hooves, scales and stratum corneum are the richest sources of keratin as shown in Figure 2.[22]

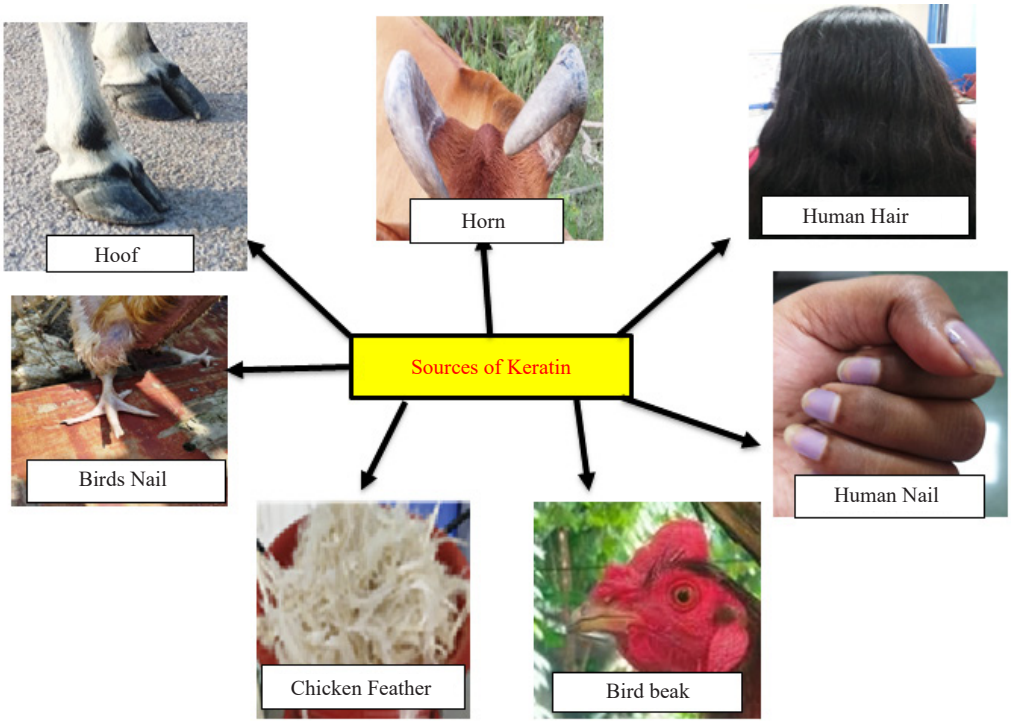


Figure 2. Sources of keratin

Human hair contains keratin protein, which provides flexibility, strength and durability to the hair in various conformations.[23] The keratin protein content of a bird's feather is approximately 99% and it is created as waste by the poultry processing industry.[24] Human hair is a natural filamentous biomaterial that contains approximately 80% of keratin protein.[25] Hair accumulation causes numerous environmental issues and is regarded as waste protein.

Feather protects birds from the environment such as cold, rain, sun exposure and injury. The chicken feather is constituted of 90% keratin which is a protein. Helical coils are linked together by disulfide bonds. It can harsh environmental conditions and is degraded by proteases because of these structural characteristics. Feather is classified as biological waste, having environmental concerns.[26] A highly cross-linked keratin network, a protein containing a considerably level of sulphur (3.8%) and many disulfide bonds made up the human nail, which is an important organ of the human body.[27] Bird's beaks have an exterior hard keratin shell that is almost entirely made up of protein.[28]

Hoof keratin is structurally complex with α-helical conformation and the sheet admixture and it has high thermal stability.[29] Due to sulphur cross-linkages the horn is a strong animal tissue with an inflexible structure. Keratin-free amino acids, peptides and lipids are an essential components of any horn as microelements like calcium, aluminum, copper, iron and zinc. The tough fiber protein in animal horn is keratin and its treatment is extremely complex.[30]

4. Major sources and effect of keratin waste on the environment and human health

The industry has become an important part of society and waste generation is unwanted by-product of the development of commercial chicken processing factories, leather industries, wool industries, textile industries and slaughterhouses (Figure 3). All produce a significant amount of keratin waste. This waste would risk it may cause environmental risk.[31]

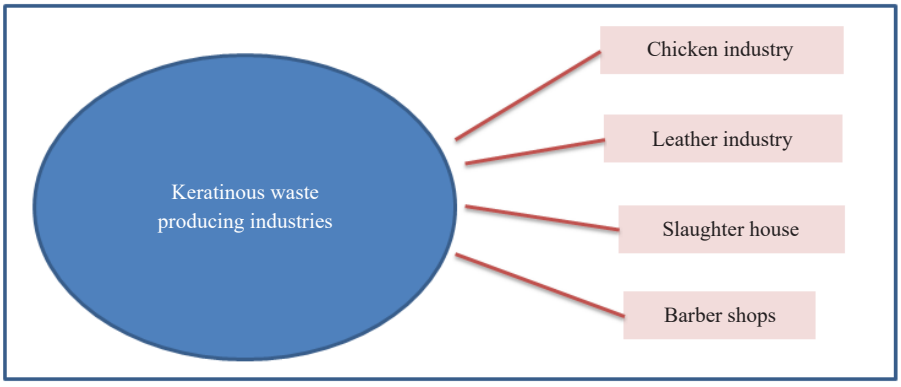


Figure 3. Major keratin waste producing industries

• ***Waste keratin from the chicken industry-*** Feather from chicken is generated as a waste by-product of the poultry processing factory in a massive amounts. Around 8.5 billion tonnes of poultry. Feather is produced annually worldwide, with India contributing 350 million tonnes. The accumulation of chicken feathers will contaminate the ecosystem. Chicken feathers pollute the environment and have a negative impact on the lives of those who live in surrounding areas.[32]

• ***Waste keratin from slaughterhouses-*** Chicken feathers, beaks, and a mixture of bones, organs and hard tissues are all examples of keratin waste produced by the meat industry (slaughterhouses). Keratinous waste degrades slowly in nature. Acidification of soils, eutrophication and a loss in species variety was all concerns caused by contaminated wastewater created by such companies.[33]

• ***Waste keratin from the leather industry-*** The leather industry is the most polluting industry on the earth. The

manufacturing of leather has a negative influence on the environment.[34] Keratin wastes created in vast quantities by the leather industry comprise either solid or liquid waste. The majority of which is animal origin, dispose of a significant amount of keratin waste such as hair, horns and hoofs.[35]

• ***Waste keratin from barbershops-*** Barber shops and hair salons are also major sources of keratin contamination human hair is regarded as an environmental pollutant and is commonly found in municipal garbage around the world.[36] Hair is thrown away in surrounding rural places, where it decomposes over several years. Hair dust is created from open hair dumps, which causes injury to those who live in that region and if inhaled in high amounts can cause many types of breathing problems.[37]

5. Different methods for treating keratin waste

Many countries throughout the world are concerned about the management of keratin waste produced in poultry, leather and slaughterhouse industries. In the last few years, a variety of approaches including hydrothermal, chemical, enzymatic and biological treatment have been researching to improve the digestibility of feathers.[38]

• ***Hydrothermal process-*** For the breakdown of keratin wastes, the hydrothermal process typically uses high temperature (80-140 °C) and high steam pressure (10-15 psi) for the breakdown of keratin wastes acid or bases.[39] This process requires a lot of energy and acid or base to break down peptide bonds. Feather degradation took a longer period. When using hydrothermal hydrolysis trypsin, pepsin and papain do not break down. Keratin protein in its natural condition because it contains the large number of disulfide bonds.[40]

• ***Chemical process-*** Chemicals (acid, base and catalyst) are used in the chemical hydrolysis of keratin wastes. Chemical hydrolysis involves more active reaction conditions (high temperature and pressure) and possesses a greater environmental risk.[41] Chemical process needs more time, chemical and energy to process as well as expensive industrial equipment because it includes a limited level of abundant amino acids, the product has a low nutritional value. This hydrolysate solubility and stability are determined by the degree of protein breakdown.[42]

• ***Biological process-*** The various procedures for the treatment of keratin waste are polluting and have a high thermo-energetic cost, hence microbial degradation/biological process is the best option. An alternate strategy that is both cost-effective and environment-friendly.[43] Microorganisms produce keratinase enzymes, which could be used to break down keratin waste into nutrient-rich animal feed.[44] Only a few microbes use keratin as a source of nutritional sustainability for growth through enzymatic digestion. Keratinophilic microflora is the name given to these microorganisms. Keratinophilic microflora is a prominent component of soil and an essential group of fungus, bacteria and insects that are easy keratinases to destroy very stable animal protein on earth.[45]

6. Different ways to benefit from keratin-containing residues

In addition to the accumulation of human hair in waste treatment facilities worldwide, roughly 24 billion of chickens are killed each year and an enormous amount of poultry feathers are produced globally.[46-47] Environmentally damaging pollutants are keratin solid waste produced by meat, poultry, fish and wool industries effective and prompt treatment of keratin waste is now required as a result of the presence of harmful bacteria in the trash.[48] In many nations there is a significant solid waste problem due to the enormous amount of keratin waste.[49] The keratin wastes are associated with the introduction of pathogens and smells into the water and environment linked to the keratin waste.[50] It can be difficult to properly dispose of keratin waste. There are four ways to dispose of keratin waste: Mechanical Grinding, Landfilling, Composting and Burning in Figure 4 below.

• ***Mechanical grinding-*** keratin waste is disposed of by mechanically converting it into usable items. The chicken feather undergoes hydrolysis under pressure and heat in this process, which is followed by grinding and drying. The waste was dried out, pounded into a powder and then transformed into useful goods.[51] The crushed powder can be utilized as an organic soil enhancer or as a source of nitrogen for animal feed primarily ruminants.[52] The mechanical grinding technique has some drawbacks several important amino acids are lost when materials are heated to an extremely high temperature and ground.[53]

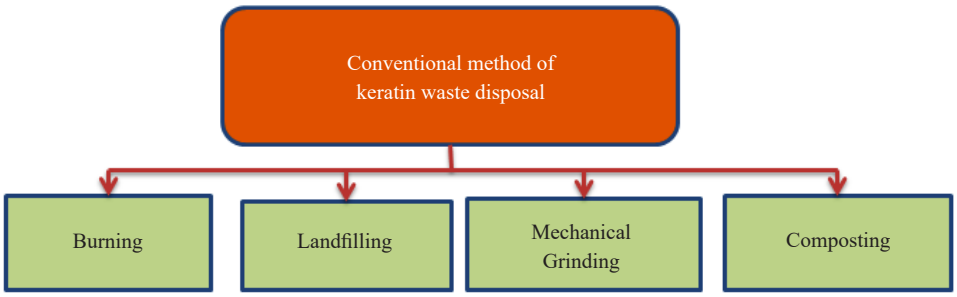


Figure 4. Conventional method of keratin waste disposal

• ***Burning-*** Burning waste burns during incineration, which also eliminates potential pathogenics, and pathogens.[54] The majority of garbage is transformed to CO_2 and water in incinerations, which operates at a temperature above 850 °C.[55] The high temperature required makes running costs both expensive and challenging to manage. Incineration causes the pollutants to be released into the air, which gives off an unpleasant smell and contributes to a hazardous runoff which has an adverse effect on the upstream and downstream areas including animals and adjoining ecosystem.[56]

• ***Landfilling-*** Landfilling is the conventional procedure for getting rid of keratin waste.[57] A landfill has historically been the most widely used technique for disposing of organized trash and they are still used in a number of locations worldwide.[58] The incorrect landfilling of keratin waste causes environmental harm and the spread of illnesses.[59] Leachate from landfills and greenhouse gases are the additional issues causing landfilling.[60] Leachate raises the nitrogen level in the area, which causes algae blooms and damages the environment.[61] Therefore, landfilling is a less expensive but ineffective technique to dispose of keratin waste.

• ***Composting-*** The assumed way for recycling feather waste is composting crude keratin protein makes up 90% of feather wt. and it also contains 15% Nitrogen.[62] Composting is an aerobic biological process that breaks down the organic waste from meat, manure and litter. Pathogens are reduced during this process and the resulting compost can be utilized as a soil fertilizer.[63] Because of the enormous production of toxic gases and potential risk to the environment, the disposal of keratin waste produced by burning, landfilling, composting and mechanical grinding is banned.[64] The management of keratin waste using microbes looks to be the promising solution, thus, encouraging scientists to research in this sector in the context of the drawbacks of their previous approaches.

7. Different methods of extracting keratin

The most widely used techniques for extracting keratin from materials rich in keratin includes Reduction, Oxidation, Alkali extraction, Microwave irradiation and Steam explosion given in Figure 5 lists the principal techniques for solubilize and extract keratin.

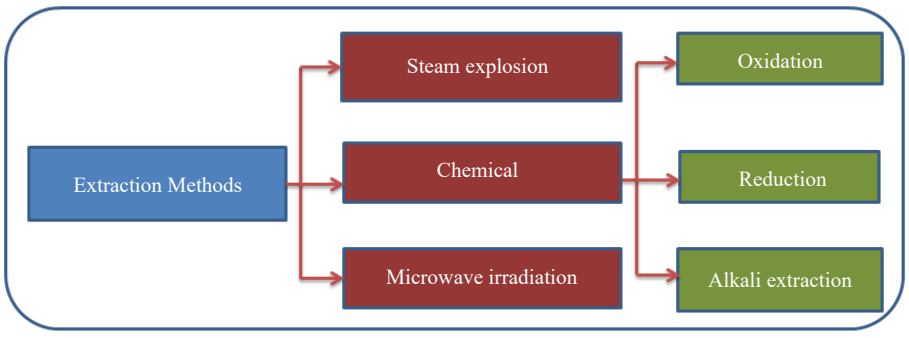


Figure 5. Extraction method of keratin

• ***Reduction method-*** Chemical containing thiol can be used to reduce overall disulfide linkage in stable keratin structure. Different processing conditions have been used for a number of reducing agents.[65] In the section that follows various compounds are employed in this reduction process. Thiols were reportedly first used as a reducing agent between 1930-1940. In early investigations, different amounts of sodium thioglycolate and thioglycolic acid were utilized to reduce wool keratin.[66] Variations in PH were found to have an impact on how much keratin was reduced in several studies.[67] When the concentration of thiol was low, it was discovered that the degree of reduction of each compound was comparable the highest extractability of 75% was recorded by the authors and it was proposed that 96 percent of wool cysteine could be reduced.

• ***Oxidation method-*** In early research on keratin extraction using oxidation.[68] For the extraction of keratin, he combined HCL, mild ammonia and peracetic acid (2%) keratin was primarily extracted for hair and wool using an oxidation technique. All investigations found that the keratin component of the wool was intractable because the extraction method did not completely dissolve it. α keratin makes up the majority of the keratin that is totally soluble extended beta sulfide. Keratin is likewise reported to be less soluble than alpha form.[69] Wool was treated to 2 percent peracetic acid for 30 hours in another investigation and it was shown that disulfide linkages were converted to sulfonate groups.[70] Later to justify these findings carried out by infrared study and discovered cysteine monoxide, dioxide and sulfonate groups.[71] So all the disulfide transformation was primarily engaged in this oxidation process to sulfonate.[72]

• ***Alkali extraction-*** Due to the possibility of cysteine residue degradation and sulphur nucleus breaking upon exposure, hot alkali solution with high concentration has a high potential to solubilize wool.[73] The primary limitation of this technology is that it cannot be utilized for commercial reasons on a large scale due to the significant volume of alkali chemicals needed during the procedure and damage due to the polypeptide chain structure of keratin.[74] The quantity of NaOH needed for keratin extraction can be decreased by utilizing a potent alkali solution. However, the residual wool from this reaction of NaOH and sodium sulfide had significant sulphur content of 11-17 percent and 7 percent of cystine must be preserved during the entire extraction process since they easily breakdown in the presence of alkali solution.[75] The two primary products of cystine breakdown are oxalic and pyruvic acid. The yield of protein recovery following alkali treatment was observed.[76] The final extracted keratin from this approach exhibited a significant levels of lysine, methionine and glutamic acid but low level of serine, arginine and cystine.

• ***Steam Explosion-*** Manson was the first to develop this steam explosion technique in 1928.[77] The results were heavily influenced by a number of relevant parameters including temperature, time, resistance, particle size and moisture.[78] For the production of bio-based materials such as delignification of wood, bioconversion of barley, pulping of lignocellulosic biomass and sugar extraction from maize starch.[79] Steam flash explosion a green hydrolysis process is frequently utilized. The bioconversion of cellulosic was utilized to remove keratin from wool in 1982.[80]

• ***Microwave irradiation-*** The primary function of microwave irradiation in this technique is to heat of solution which shortens the processing time. An extraction yield of about 60% was achieved using this technique.[81] The microwave irradiation technique is easier than the traditional steam processing method. The main problem with this method is that after about 90 min of treatment, the final keratin sample made from wool significantly loses the amino acids like cysteine. When compared to the uneven, non-uniform heating present in the traditional heating. Due to the complicated keratin structure, there is currently a lack of knowledge on the interaction of electromagnetic radiation with a wool matrix. However, it is hypothesized that less energy is needed for activation because of the hydrolysis of the ester group.

8. Characteristics & properties of keratin

Keratin has a hierarchical three-dimensional fibrillar structure.[82] It is made up of tiny, nanometric amino acids that polymerize in the expected way. The sequence corresponds to a protein with a molecular weight of 100 nm. Feather keratin has a molecular weight of about 10,500 Da. The percentage of cysteine in an amino acid sequence is 7% according to the amino acid keratin has approximately 40% hydrophilic and 60% hydrophobic chemical compounds in its structure due to its acid sequence. Protein molecules can form α-helix, β-helix, or a random non-sequential macrostructure. In feather the keratin filament consists of alpha helix, beta helix and random structure make up of 41%, 38% and 21% respectively. Intermolecular hydrogen bonds exist between one amino acid carbonyl group and a amino

group of another amino acid in the α helix structure. The structure of beta sheet is defined by amino and carbonyl groups formed by interchain hydrogen bonding water molecules in the protein structure can be combined to form hydrogen bonds.[83] Keratin has a high level of stability due to intermolecular bonding between polar and non-polar amino acids as well as a low level of solubility due to the existence of s-s cysteine bonds.[84]

High content of amino acids such as glycine, alanine, serine and valine distinguish keratin also contains a minor amount of methionine, lysine and tryptophane in its composition sulphur containing amino acids cysteine is the most prominent component (7-12%). One of the cysteine carbonyl groups from the peptide chain, whereas another group amino acid and carbonyls form peptide bonds within another peptide chain. Keratin chemical activity is mostly dependent on cysteine which is hydrolyzed, oxidized and reduced. The different compositions of amino acids in keratin are shown in Table 1.

Table 1. The composition of amino acids in keratin from various sources

Type	Amino acid	Keratin (%)
Non-ionic polar amino acids	Cysteine	7.81
	Threonine	4.12
	Serine	14.12
Ionic polar amino acids	Lysine	0.80
	Alanine	8.75
	Phenylalanine	3.15
Non-polar amino acids	Glycine	13.80
	Valine	7.90
	Methionine	0.11

Ionic and non-ionic amino acids are categorized as polar or non-polar covalent bonds formed by cysteine which contains sulphide and disulphide bonds. Non-ionic polar amino acids like threonine, and glutamine form hydrogen bonds. Ionic effects are caused by ionic amino acids such as glutamic acid, lysine and arginine. The influences on non-polar amino acids (methionine, proline and phenylamine) are non-polar.[85] Keratin reactivity is influenced by a variety of circumstances the chemical composition, morphological structure and intermolecular linkages of the active keratin group are some of the most important factors the solubility, water susceptibility to other substrates and mechanical parameters of keratin also influence its reactivity.[86] The presence of hydrogen, ionic and covalent bond in the protein influence the following parameters making hydrogen bond with hydrogen molecules is one of the impacts. Hydrogen bonds have a lower energy than ionic and covalent bonds but they have higher energy than hydrophobic influence the =NH and =C-OH groups can form hydrogen bonds. The presence of different groups in the keratin structure allows it to take part in a variety of processes. Proteins, including keratin, may undergo various chemical modifications, as shown in Figure 6.

9. Application of keratin

Keratin has only been utilized for a few applications due to its water insolubility and limited extraction and processing methods. It was previously used as a biomaterial in regenerative medicine. In recent years, there has been a rise in interest in keratin and its derivatives, including keratin derived from wool.[87] Chicken feather is usually made

up of hydrophobic keratin a protein that has a similar strength to nylon but smaller in diameter than wood fibers. The semi-crystallinity and crosslinked structure of chicken feather fiber improve the resistance of polymer-based composites to mechanical strain. In addition, the extension coefficient of chicken feather fiber is high. The above characteristics suggest that the chicken feather fiber could be used as polymer reinforcement.[88] The pharmaceutical, medical, cosmetic and biotechnology industries all have a significant interest in keratin. Porous foam in various shapes, sponges, cushioning layers, coating, gels, micro fibers and high-weight material can all be made from keratin compound derived from wool. Non-antigen keratin aids wound healing and tissue repair. The surrounding tissues can be absorbing the keratin implant layer, structure, or biomaterial. Wound healing, tissue regeneration, cell seeding, and diffusion are all possible applications for soluble keratin. Table 2 shows the source wise application of keratin like, food cosmetology, medicine, textile, composite, agriculture and other industries use keratin from feathers to make film, fibers, hydrogels, and micro and nanoparticle.[89]

Table 2. Application of different sources of keratin

S. No.	Sources	Application	Ref.
1-	Human hair	Medical usage	90
2-	Wool	To investigate the biological and structural characteristics of self-assembled keratin	91
3-	Horns and hoof	Biomedical application, tissue engineering, Composites and aerospace application	92
4-	Chicken feathers	Delivery of drugs	93
		Newly grown fibers	94
		Nano and micro-particles	95
		Pharmaceutical nano-particles	91
		Graphene oxide and related compounds for biomaterials	96
		Feeding supplement for ruminants	97
		Food packaging	98
		Textile yarns	99
		Fabrication of bio-composites	100
		Bio-fertilizer, Thermoplastic films for food packaging, hydrogels	101
		Used while making paper	102
		Chicken feather and Polypropylene are utilized as a non-woven insulator	103
5-	Wool	Nanofibres, Antipilling processing, porous foams	104
6-	Sheep wool	Carpet industry, Apparel, Regenerative medicines and coating	105

Keratin-based biomaterials have received substantial research over the past few decades for their outstanding biocompatibility and biological characteristics. As a result, keratin-based biomaterials can offer a biocompatible matrix for the regrowth and regeneration of dead or damaged tissue. Keratin has the ability to simplify cell adhesion, proliferation, and tissue regeneration.[106] Keratin-based biomaterials have the potential to be used in wound healing, hemostasis and nerve restoration. In Figure 7 several uses of keratin are described.

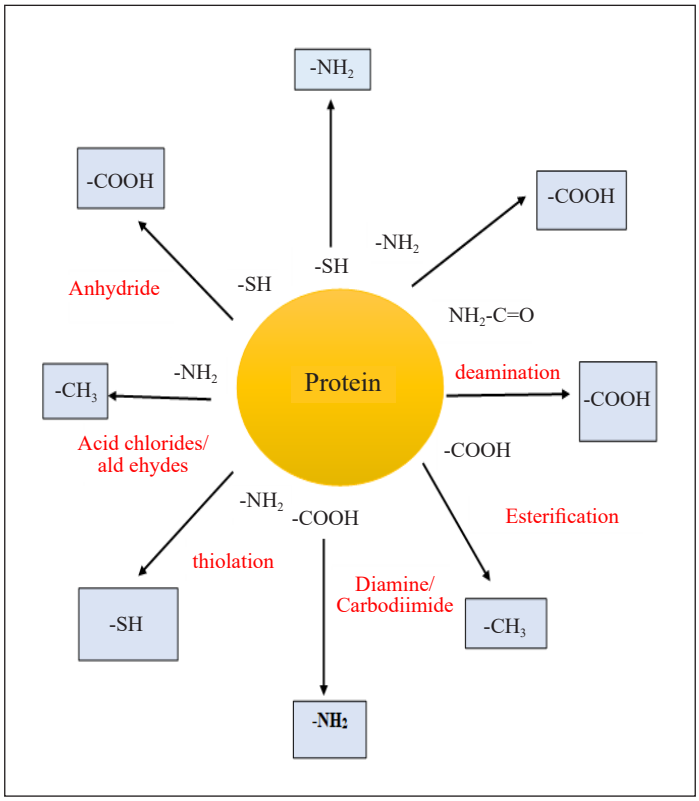


Figure 6. Proteins chemical modification

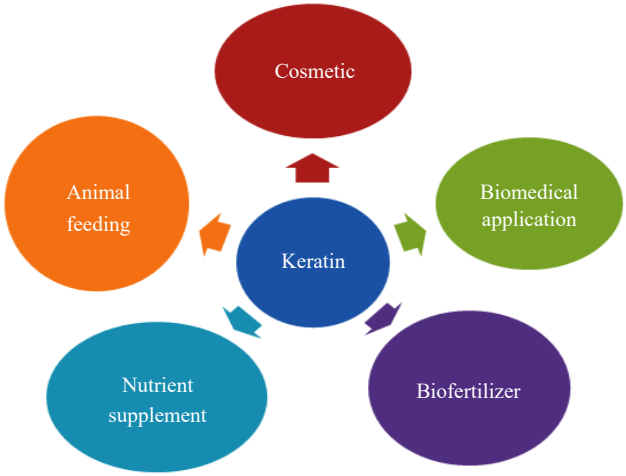


Figure 7. Applications of keratin in different areas

9.1 *Biomedical application*

The mechanical durability, biocompatibility and biodegradability of keratin-based material are excellent. In the area of contemporary biomaterials, these unique features have inspired a revolution. These materials are easily converted into intricate 3-D sponges, film, hydrogel and other materials for a variety of biomedical applications.[107] Hydrogels made of keratin have shown promise in a variety of biomedical applications. The potential to slow the course of burns and encourage skin regeneration has been demonstrated for keratin hydrogel (purity 9%). It has been demonstrated

that a concentration of 15% is effective for nerve generation and recovery.[108] In order to create a scaffold for dental tissue engineering keratin polymers have been used. Hydrogels with 20% keratin and 3% glycerol concentration have improved cell behaviour and shown promising results in pulp dentine regeneration as they effectively transmit light and high mechanical strength, keratin films are the superior alternative for reconstructing ocular surface in Figure 8.

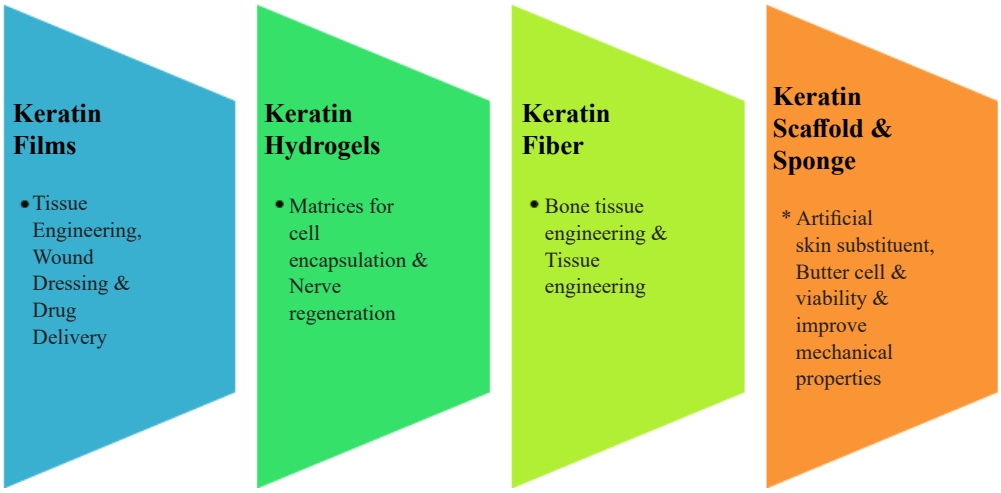


Figure 8. Keratin core biomedical application

9.2 *Biosorbents*

Heavy metals removal from water is facilitated by keratin biomaterials. These biomaterials function via physical and chemical surface mechanisms that are active Polar Regions to attract charge metal ions. Biosorbents, keratin is collected from distinct sources including chicken feathers, human hair and animal horns. Metal ions such as Cd, Ni, Cr, Zn and Br are adsorable using keratin from chicken feathers. Metals Pb (II) and Pb (I) are absorbed using keratin that has been isolated from wool & feather respectively.[109]

9.3 *Cosmetics*

The keratin hydrolysates are utilized in a variety of aesthetic procedures, including those on skin and hair. The keratin supplements increase the moisture in hair moisturisers and have a moisturizing effect on the skin.[110] Keratin is compatible with water and enhances the mechanical and thermal characteristics of hair, supporting the use of its cosmetic goods. Keratin peptides can increase the effectiveness of the skin barrier and less transpidermal moisture loss, keeping the skin smooth and elastic. Keratin protein that has been dissolved form bonds with natural nails and reinforce the nail plate.[111] Bath soaps include hydrolyzed keratin in a concentration of 0.2% respectively.

9.4 *Biofertilizers*

Due to the carbon and nitrogen content keratin wastes are employed as organic fertilizers. It can be made from keratin a dependable supply of nitrogen. Given that it is a high source of peptides, minerals and amino acids feather waste makes a good fertilizer. The feather hydrolysate has been discovered to be effective in crop cultivation since it can improve contaminated soil and can improve plant growth.

9.5 *Miscellaneous applications*

Human hair keratin is used to make plasters of walls in homes and other structures.[37] Electrical components

including resistors, capacitors and inductors and produced from keratin-derived biodegradable polymers in Figure 9 illustrate the applications.

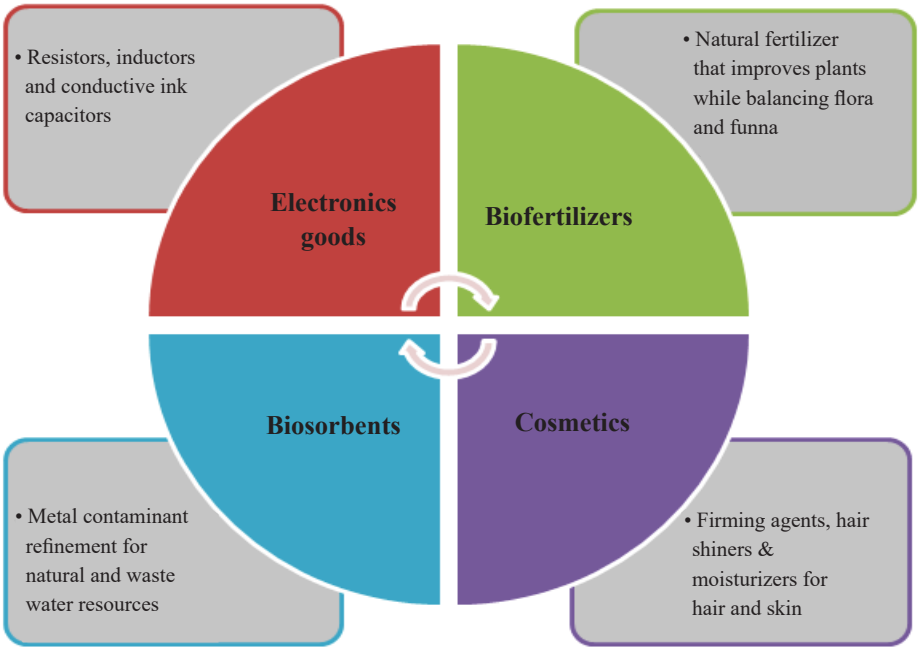


Figure 9. Various applications of keratin

10. Conclusion & future perspectives

According to the literature review conducted to date, keratin is crucial for the creation of several products with value added. On a big scale, the waste biomass that is generated by the food industry and from the animals can be used as a substrate or raw material for the production of keratin. In addition to sparing the ecosystem from a lot of sludge, the management of keratin-based waste biomass by reconversion into commercially useful products would also financially benefit the pharmaceutical and cosmetic industries. Finally, an environmentally safe way to extract keratin biomass that uses the fewest hazardous acids and chemicals is now necessary. One of the research areas that still have to be investigated is the utilization of keratin biomass for the development of biofertilizer, chemical fertilizers that alters the microorganisms and productivity of cropland fields can replace with biofertilizers. As a result, the present review provides important details on the sources, potential, uses and unexplored research entities for keratin-based biomass.

Conflict of interest

The authors declare there is no conflict of interest.

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