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REVIEW ARTICLE

Extraction and application of keratin from natural resources: a review

Chaitanya Reddy Chilakamarry[1] · Syed Mahmood[2] · Siti Nadiah Binti Mohd Saffe[3] · Mohd Azmir Bin Arifin[1] · Arun Gupta[1] · Mohamed Yacin Sikkandar[4] · S Sabarunisha Begum[5] · Boya Narasaiah[6]

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Abstract
Over recent years, keratin has gained great popularity due to its exceptional biocompatible and biodegradable nature. It has shown promising results in various industries like poultry, textile, agriculture, cosmetics, and pharmaceutical. Keratin is a multipurpose biopolymer that has been used in the production of fibrous composites, and with necessary modifications, it can be developed into gels, films, nanoparticles, and microparticles. Its stability against enzymatic degradation and unique biocompatibility has found their way into biomedical applications and regenerative medicine. This review discusses the structure of keratin, its classification and its properties. It also covers various methods by which keratin is extracted like chemical hydrolysis, enzymatic and microbial treatment, dissolution in ionic liquids, microwave irradiation, steam explosion technique, and thermal hydrolysis or superheated process. Special emphasis is placed on its utilisation in the form of hydrogels, films, fibres, sponges, and scaffolds in various biotechnological and industrial sectors. The present review can be noteworthy for the researchers working on natural protein and related usage.

Keywords Keratin · Sheep wool · Feathers · Proteins · Amino acids

Introduction

Keratin belongs to the family of fibrous structural proteins called scleroproteins. It is the most abundant structural protein found in hair, nails, feathers, horns, claws of animals; along with collagen, it is the most important biopolymer encountered in animals. Its characteristic feature is its high cysteine content as compared to other fibrous proteins like elastin, collagen and myofibrillar protein (Feroz et al. 2020). Several studies have been conducted on various extraction, purification, characterisation and application of keratin proteins. Over the years, keratin has been extracted from chicken feathers, beaks, claws, nails, horns, hooves, human hair and toenails. The other significant source of keratin is wool. Wool with up to 95% keratin by weight is considered to be a pure source of intermediate filament proteins, which have gained importance in cosmetic and biomedical fields. Keratin biomaterials prepared from wool and human hair possess cell-binding motifs which have hemostatic and cell-binding potential. Keratin has an intrinsic ability to self-assemble and form polymers. These biomaterials are exceptionally biocompatible and have cellular proliferation abilities, making them a great candidate for drug delivery systems and tissue engineering (Idrees et al. 2020). They have also found potential roles in energy sectors, agricultural fields, pharmaceutical and cosmetic industries, leather and textile industries (Donato and Mija 2020). The significant keratin sources are described in Fig. 1, and their applications are listed in Table 1.

✉ Syed Mahmood
syedmahmood@um.edu.my; syed872011@yahoo.co.in

1 Faculty of Chemical and Process Engineering Technology, Universiti Malaysia Pahang, 26300 Gambang, Pahang, Malaysia

2 Department of Pharmaceutical Technology, Faculty of Pharmacy, University of Malaya, 50603 Kuala Lumpur, Malaysia

3 Faculty of Manufacturing and Mechatronics Engineering Technology, Universiti Malaysia Pahang, 26600 Pekan, Kuantan, Malaysia

4 Department of Medical Equipment Technology, College of Applied Medical Sciences, Majmaah University, Al Majma'ah 11952, Saudi Arabia

5 Department of Chemical Engineering, Sethu Institute of Technology, Kariapatti 626115, Tamil Nadu, India

6 Department of Physics, Indian Institute of Technology, Tirupati 517506, Andhra Pradesh, India

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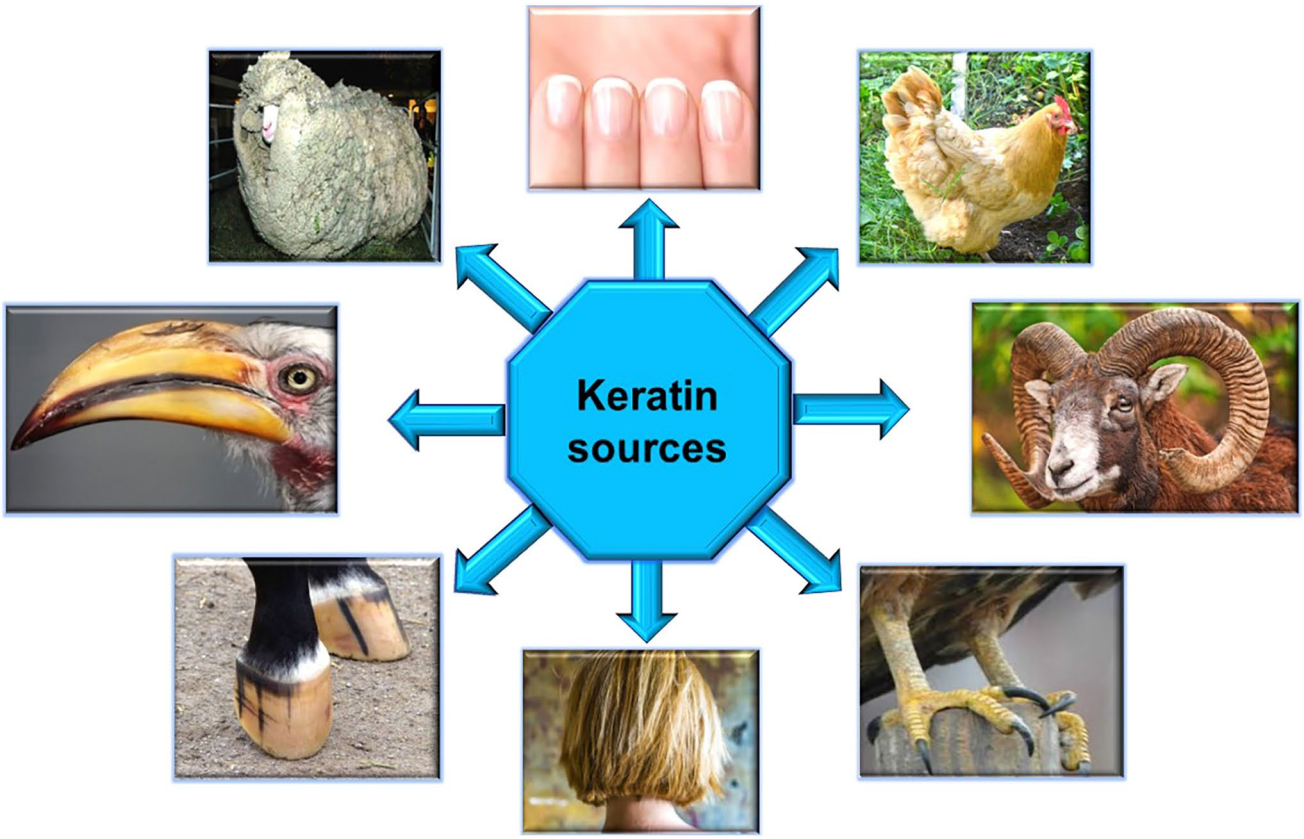

Fig. 1 Major sources of keratin

Table 1 Keratin sources in various applications are described below

S. No	Keratin sources	Application	References
1	Chicken feather	Bioplastic films, Biofertilizers, Bio-composites Cosmetics, Composites in automobile and aeroplanes. Hydrogels Thermoplastic films for food packaging. Diet supplements leather and textile processing. Waste management	Donato and Mija (2020)
2	Chicken feather	They are used to develop thermoplastic films for food packaging, printed circuit boards (PCB), and dielectric material	Donato and Mija (2020)
3	Chicken feather	Used in paper production	Tesfaye et al. (2017)
4	Chicken feather	Chicken feather with polypropylene is used as a non-woven insulator	Soekoco et al. (2018)
5	Human hair	Biomaterials, Drug permeation Films as substrate Medicinal use Tissue engineering	De Masi et al. (2019)
6	Wool	Antipilling processing, Biopolymer, Hydrogel Medical science, Nanofibers, Sponges and porous foams	De Masi et al. (2019)
7	Sheep wool	Thermal insulation of external walls, concrete slab floor	Parlato and Porto (2020)
8	Sheep wool	Wool fibre as reinforcement in concrete, carbon fibre precursor	
9	Sheep wool	Apparel, carpet industry	Gong et al. (2016)
10	Sheep wool	Regenerative medicines, bioplastics, coatings or packaging	Fernández-d'Arlas (2019)
11	Bovine hoof	Hoof bovine is compatible material used for promoting cellular attachment. Hence used in biomedical and tissue engineering	Kakkar et al. (2014)
12	Bovine hoof, horn	Aerospace application, engineered composites	Baillie et al. (2000)

With the rapid increase in urbanisation, millions of tons of keratin-containing biomass are released into the environment by food industries, particularly meat, slaughter and wool industries (Sharma and Gupta 2016). Large

amounts of keratinous wastes are dumped, landfilled and incinerated throughout the world, resulting in environmental pollution. Thus, there is an urgent need to find efficient ways to treatment of these waste products. Studies have suggested that biological degradation of keratin waste is considered to be more efficient than the physical and chemical methods, yielding useful by-products that have immense commercial applications.

This review focusses on the structure of keratin, its classification and its properties. The various extraction processes have been reviewed in brief with an emphasis on the medicinal application of keratin.

Keratin: structure, classifications, and properties

Keratin is one of the most important structural proteins found in certain epithelial cells of vertebrates, belonging to the intermediate filament protein's superfamily. Keratin proteins are fibrous with long polypeptide chains and cross-linking fibres (Murray et al. 2017). Polypeptide chains form the basic macromolecular structure of keratin. These chains curl into helices giving rise to α-conformation or bond side-by-side into pleated sheets forming β-conformation. Thus, structurally keratins can be classified as α- and β-keratins, with β-keratin being tougher than the α-form. The α-form is found in mammals and is the primary constituent of wool, hair, claws, hooves, horns and stratum corneum. In contrast, the β-form is mainly found in hard avian and reptilian tissues, such as feathers, beaks and claws of birds, and scales and claws of reptiles.

Keratins are robust in structure, highly stable and remain insoluble in most of the organic solvents. They are also resistant to enzymatic degradation by proteolytic enzymes. The high cysteine content in keratin confers mechanical and chemical resistance. Keratin protein also has a high thermal resistance, and according to Takahashi et al., it can be denatured at a temperature higher than 100 °C.

Keratin proteins are rich in certain amino acids like glycine, alanine, serine and valine. According to Strnad et al. (2011), minor amounts of methionine, lysine, and tryptophan are also present. Cysteine and cystine (containing sulphide and disulphide bonds) are responsible for creating covalent bonds and impact the physicochemical properties of keratin. The chemical modification is presented in Fig. 2.

α-helices and β-sheets comprise of ~50% of a protein's secondary structure. These are formed and stabilised by non-covalent interactions, mainly hydrogen bonds. The α-helix is formed when amino acids become tightly coiled into a right-handed helical structure. An α-helix has 3.6 residues per turn. The amino acid side chains that are three or four residues apart are held together and stabilised by the formation of hydrogen bonds between the amino and carbonyl groups of every fourth peptide bond.

In contrast, the β-sheets are made up of polypeptide chains that are folded back and forth, forming twisted and pleated sheets which are stabilised by hydrogen bonds formed between backbone carbonyl oxygen atom and hydrogen of the amino group. Hence, the long chains of keratin could be compact and rod-like, giving rise to α-conformation or stretched out into twisted and flattened β-sheets, as shown in Fig. 3 (Murr 2015).

Studies on molecular weight for both α-keratins and β-keratins have shown that the molecular weight of α-keratins is approximately 40 kDa and that of β-keratins is between 10 and 22 kDa.

Keratins can be distinguished into acidic, or basic based on their isoelectric points also referred to as pI, which is the pH at which the proteins are neutral. The pI of keratins can be changed due to post-translational modifications of their amino acids. The existence of the ionic bonds is pH-dependent. It is higher at the isoelectric point pH 4.9, where the protein exists in zwitterion form ($+H_3N–CHR–COO–$). In general, keratin is neutrally charged, and the ionic bonds are weakened under extremely acidic or basic conditions. The ionic bond exists between ammonium cations and carboxylic anions. These bonds are deprotonated by the amine group at high pH and protonated by the carboxylic groups at low pH (Feroz et al. 2020).

Over the years, keratin has been extracted by using various techniques like oxidation, reduction, sulfitolysis and superheated hydrolysis. Different samples of extracted keratin are characterised by molecular weight determination and amino acid analysis. In one study, Rajabinejad et al. (2019) compared the amino acid content of extracted samples with original wool. The details are listed in Table 2, and the chemical structures of an amino acid are presented in Fig. 4

During hydrolysis of keratin, amino acids undergo degradation and conversion. For instance, tryptophan is destroyed. Other amino acids like cystine, cysteine, methionine and tyrosine undergo partial degradation, whereas asparagine and glutamine are converted into aspartic and glutamic acid, respectively. During various extraction methods, cystine disulfide bonds are cleaved resulting in the production of low molecular weight proteins and peptides as new residues. The significant change in amino acid composition is of cytisine and cysteine to cysteic acid.

Extraction methods of keratin

Dissolution and extraction of keratin is a difficult process. Finding an efficient, eco-friendly and cost-effective method is of prime importance. Recent years have witnessed advances in the extraction and characterisation of keratins,

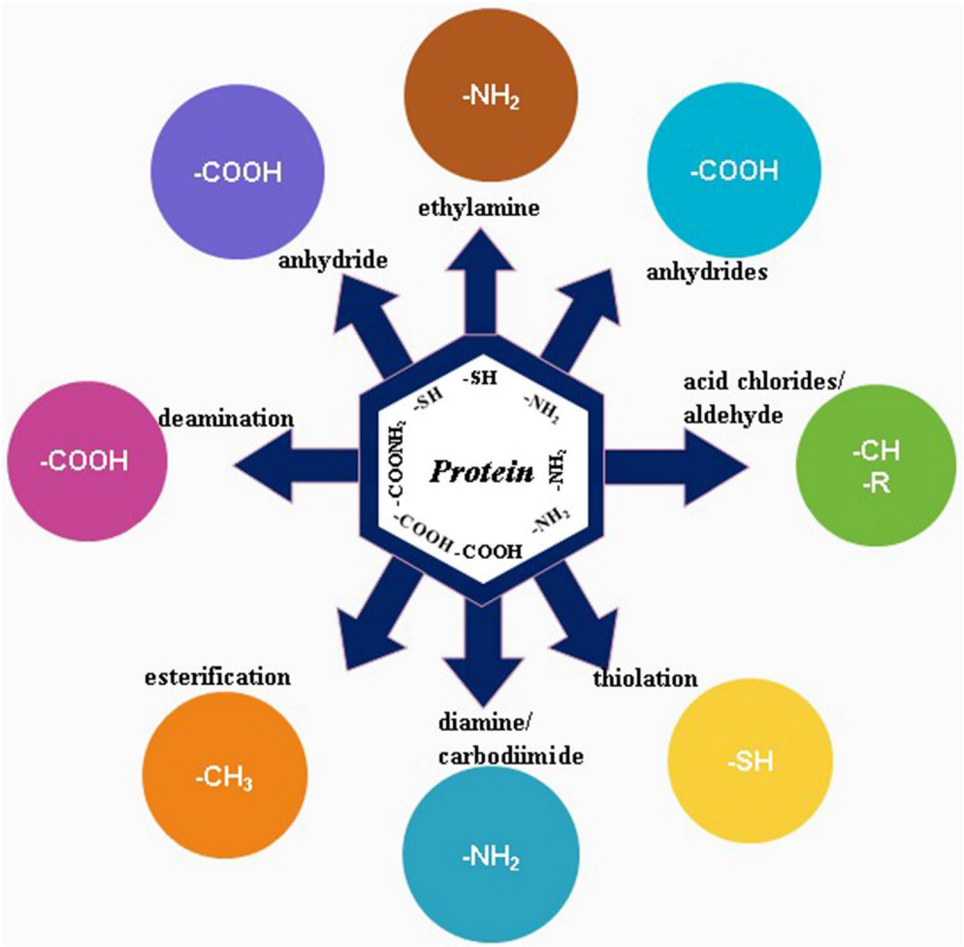

Fig. 2 The possible chemical modifications of proteins, including keratin

leading to increased production of keratin-based materials. These materials are extensively being used in cosmetic, pharmaceutical, leather and agriculture industries.

Keratin can be extracted using several methods such as chemical hydrolysis, enzymatic and microbial treatment, dissolution in ionic liquids, microwave technique, steam explosion technique and thermal hydrolysis or superheated process.

Chemical hydrolysis

Acidic hydrolysis is highly efficient, but the residue obtained has low nutritional value as some amino acids like tryptophan are lost in the process. In alkaline hydrolysis, the loss of amino acids is lower. In a study it was observed that alkali hydrolysis at 80 °C with 2% NaOH for 3 h resulted in 25% yield (Seghir et al. 2020). The hydrolytic processes yield is governed by pH, temperature and reaction time, and the type and concentration of acid or base used. Chemical hydrolysis is often accompanied by heating to ensure high yield; however, high temperatures tend to destroy the amino acids (Sinkiewicz et al. 2017).

Oxidation of keratin is carried out using 2% peracetic acid, mild ammonia and HCl. Also, 4.5% of sodium percarbonate has been used in many studies. The oxidation method is mainly used for extracting keratin from hair and wool. The reduction/oxidation method of extraction involves the usage of sodium thioglycolate/hydrogen peroxide. Brown et al. (2016) stated that reduction could be carried out with certain denaturing agents such as 2-mercaptoethanol or sodium metabisulfite and urea. These reagents attack the disulphide bonds, hydrogen bonds and salt linkages of the keratin fibres.

Enzymatic and microbial treatment

Studies have shown that many microorganisms help in keratin extraction by secreting keratinolytic and proteolytic enzymes called keratinases. Such microorganisms include mesophilic fungi, actinomycetes and some species of *Bacillus*. Keratinase is used for the bioconversion of keratin waste and is an industrially significant enzyme that is mainly used in textile and leather industries. Savinase enzyme is used to extract keratin from wool and feather.

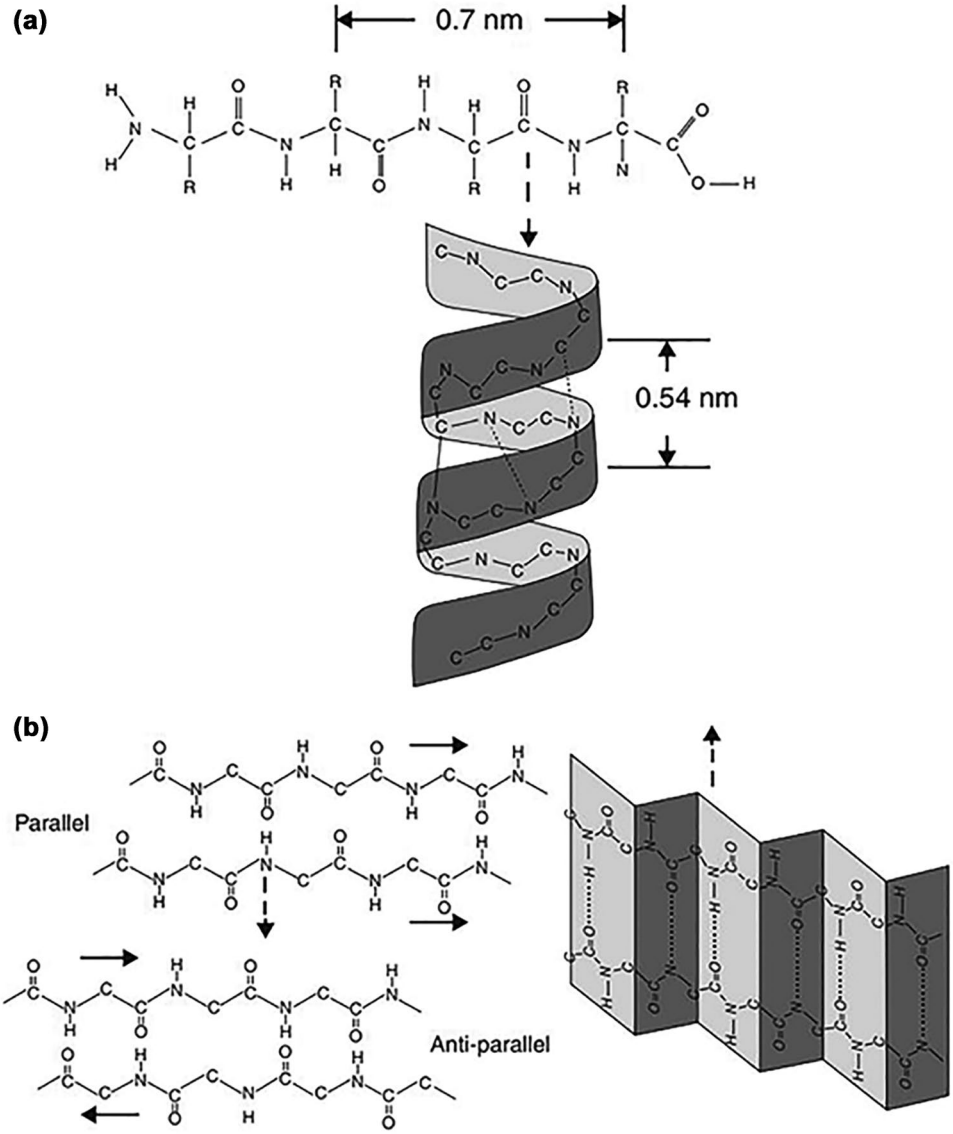

Fig. 3 Molecule structure of keratin protein; α-keratin (α-helix) and β-keratin (β-pleated sheet)

Enzymatic hydrolysis involves low usage of energy; however, it's carried out under the influence of certain reducing agents that destroy keratin's disulphide bonds. Keratin degradation mainly occurs by proteolysis, sulfitolysis and deamination. Proteolysis and sulfitolysis cause cleavage of disulfide bonds of protein to cysteine and S-sulfocysteine by means of sulfite material released by microorganisms. Deamination occurs as the microbial enzymes attack insoluble keratinous protein substrates and release free amino ($–NH_2$) group-containing molecules. This hydrolytic technique of extraction exhibits more potential than chemical or thermal treatments and has thus gained popularity in several industrial and biotechnological processes (Feroz et al. 2020). It is considered to be environmentally safe and is cost-effective.

Dissolution in ionic liquids

Ionic liquids mainly compose of organic/inorganic anions and bulky cations. These liquids have a high solvation capacity, are exceptionally durable with high melting and boiling points, and are considered to be safe solvents. They are also recyclable; as a result, they have been widely used for as catalysts, solvent for different polymers and ion conductive media. One study concluded that as compared to other anions like BF_4, Br, PF_6 chloride-containing ionic liquid served as the best solvent (Xie et al. 2005). The regenerated keratin was mainly comprised of β-sheets as the α-helix was destroyed during extraction. The extracted keratin displayed high thermal stability.

Ji et al. (2014) investigated three major ionic liquids namely 1-allyl-3-methylimidazolium chloride ([Amim]Cl), 1-butyl-3-methylimidazolium bromide ([Bmim]Br),

Table 2 Amino acid content of wool and the extracted keratin (all units in mol%)

Amino acid	Wool	Hydrolyzed keratin	Keratose	Keratin	Sulfo-keratin
Alaline (ALA)	5.7	8.3	5.8	5.6	5.2
Arginine (ARG)	5.9	5.9	6.0	6.4	6.1
Aspartic acid (ASP)	9.3	8.8	10.5	9.6	8.4
Cysteic acid (CYA)	0.2	0.2	7.8	0.3	0.4
½ Cysteine (CYS)	9.5	0.5	0.0	8.1	10.6
Glutamic acid (GLU)	15.6	19.5	17.7	15.6	14.6
Glycine (GLY)	7.3	9.0	6.7	8.1	8.1
Histidine (HIS)	0.5	0.5	0.5	0.5	0.5
Isoleucine (ILE)	2.9	2.9	2.7	2.8	2.6
Lanthionine (LANT)	0.4	2.3	0.6	0.6	0.7
Leucine (LEU)	7.1	7.9	7.3	7.6	6.3
Lysine (LYS)	4.0	3.4	3.5	3.5	2.8
Methionine (MET)	0.4	0.5	0.1	0.3	0.2
Proline (PRO)	3.1	3.7	3.2	3.2	4.2
Phenyl alanine (PHE)	1.8	1.6	1.6	2.0	1.7
Serine (SER)	11.7	10.7	11.6	11.0	11.9
Threonine (THR)	6.8	6.2	7.0	6.6	7.5
Tyrosine (TYR)	2.5	2.4	2.2	3.0	2.7
Valine (VAL)	5.5	5.8	5.3	5.3	5.1

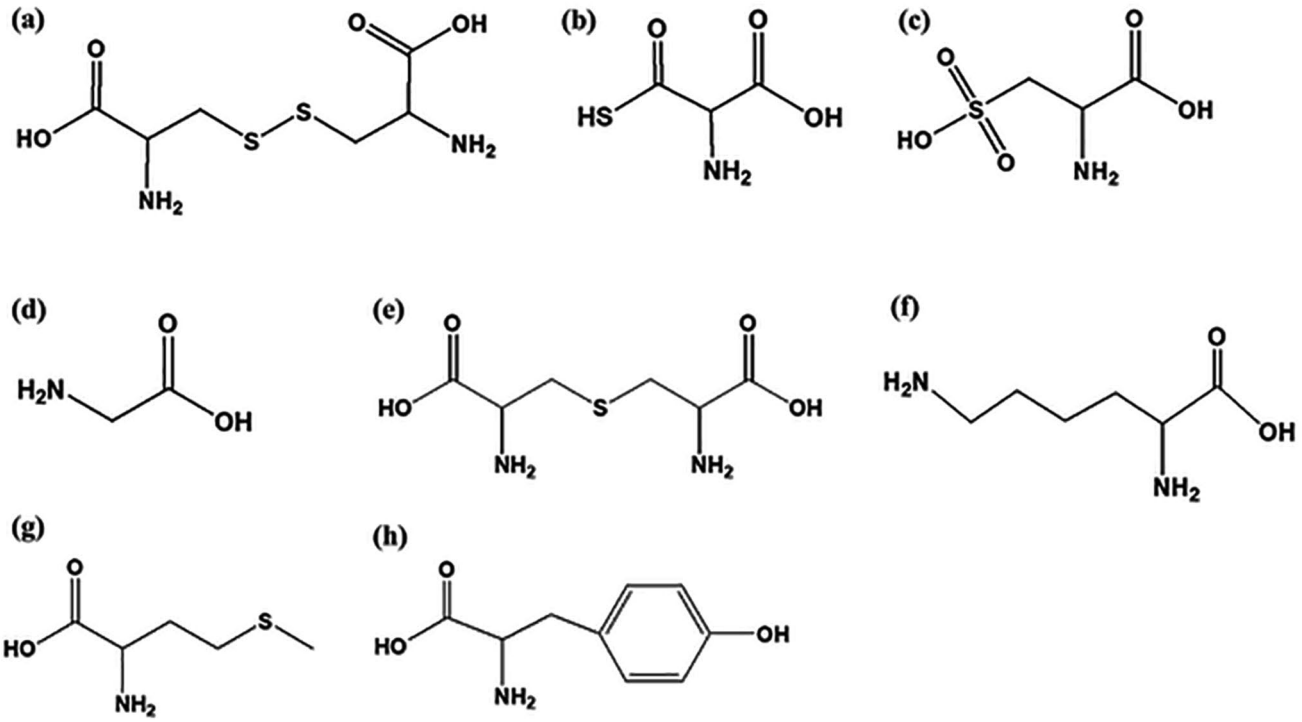

Fig. 4 Chemical structures of amino acids. **a** Cystine. **b** Cysteine. **c** Cysteic acid. **d** Glycine. **e** Lanthionine. **f** Lysine. **g** Methionine. **h** Tyrosine

1-butyl-3-methylimidazolium chloride ([Bmim]Cl). To facilitate the breakdown of the disulfide bonds, Na_2SO_3 was added. It was again noted that chloride-containing ionic liquid was the best solvent for keratin dissolution due to its high nucleophilic activity and chloride ion concentration which are responsible for breaking the hydrogen bonds.

It was demonstrated in a study that [Bmim]Cl exhibited a yield of 57% during an extraction process carried out at 120 °C for 30 min with a weight ratio of 1:6. Under similar conditions with weight ratio 1:10 it showed a yield of 78.5%. It was reported that another ionic liquid, 1-ethyl-3-methylimidazolium diethyl phosphate [Emim]DEP exhibited a yield of 70.2% at 120 °C for 30 min with weight ratio of 1:10 (Seghir et al. 2020).

Ghosh et al. (2014) examined the consequence of temperature on keratin dissolution and its yield. Dissolution was observed at various temperature settings of 120 °C, 150 °C, and 180 °C in [Bmim]Cl. At 120 °C, the maximum yield of 57% was observed, whereas 35% and 18% yield were obtained at 150 °C and 180 °C, respectively. The researchers concluded that this low yield could be due to the water-soluble amino acids that remained in the ionic liquid and were not precipitated.

Microwave irradiation

In this process, the activation energy required for keratin extraction is reduced, and uniform heating is provided to the keratinous mass. It is an effective process of keratin degradation and extraction as homogeneous heating occurs within a fraction of seconds. The molecules in microwave-assisted heating tend to adsorb energy homogeneously with the rise of temperature in the reactor. Zoccola et al. (2012), used microwave irradiation at a temperature of 150–180 °C for an hour and received an extraction yield of 60%. According to Bertini et al. (2013), superheated extraction at 180 °C for 30 min exhibited a yield of 31%. Feroz et al. (2020) carried out extraction by using feathers at a temperature of 160–200 °C for 20 min and received a yield of 71.83%.

Steam explosion process

Steam explosion is a hydrothermal process that utilises high-pressure saturated steam for short intervals of 1–10 min. The keratinous biomass is maintained at a temperature of 180–230 °C in the reactor. Towards the end of the treatment, the pressure is rapidly dropped, causing explosive decompression and rupturing of the rigid biomass fibers. Various factors related to temperature, resistance time, particle size and moisture greatly affect the outcome.

Miyamoto et al. (1982), used this technique for the first time for the extraction of keratin from wool. In a study carried out by Xu et al. (2003), saturated steam at 164.2 °C was applied for 2–8 min to convert wool (80%) to pepsin digestible material. During the study, a decrease in crystallinity of the wool was noted with increased pressure. The wool samples were subjected to a pressure of 0.2–0.8 MPa, which resulted in damaging the disulfide bridges. This treatment resulted in damaging the wool surface and was not effective in breaking the disulfide linkages and hydrogen bonds (Feroz et al. 2020). Nonetheless, this technique is mainly used for the bio-conversion of cellulosic materials.

Zhao et al. (2012) suggested the steam flash-explosion technique extract wool keratin instead of conventional steam explosion. The steam flash-explosion is an advanced form of steam explosion and was developed as a pre-treatment technique to enhance the solubility of feathers in water and other solvents. During this process, the pressure of steam is maintained at 1.4–2 MPa for 30 s to 5 min, and then a sudden flash of the explosion is generated. Zhang et al. (2015) reported high extraction yield with increased pressure, however, the quality of the by-product is compromised.

Thermal hydrolysis or superheated process

The superheated process for keratin extraction from feathers was conducted in a sealed pressure cell with water at 20 mg/ml, and the preparation was placed in a pre-heated oven. This hydrolysis involves treating the biomass (with water) at various pressure and temperature conditions till protein is converted into oligopeptides. Yin et al. (2007) suggested that the rate of dissolution depends on temperature and time. Thermal hydrolysis is a two-step process involving (i) denaturation of the keratin protein network of the intermediate filaments (ii) cleavage of the disulfide bonds that connect the keratinous fibrils together. This two-step process has given a keratin recovery yield of approximately 70% (Tasaki 2020).

Application of keratin in various fields

Keratin is naturally insoluble, mechanically robust and chemically unreactive. Degradation of keratin and its disposal can cause a harmful impact on the environment. Therefore, extensive investigations focusing on keratin-waste utilisation have been conducted. According to Onifade et al. (1998), tons of horns, hair, hooves, and feathers containing keratin are wasted every year. In recent years, these wastes have been utilised to extract some important and insoluble keratin proteins at the industrial level. Polyvinyl alcohol fibres that contain keratin are being used as absorbents for toxic/hazardous substances like heavy metals ions and have immense industrial application.

Over the past few decades, keratin-based biomaterials have been investigated extensively for their exceptional biological properties and excellent biocompatibility. Keratin possesses an inherent capability to simplify cell adhesion, proliferation, and tissue regeneration; hence keratin-based biomaterials can provide a biocompatible matrix for regrowth and regeneration of dead or defective tissue (Shavandi et al. 2017). Kelly (2016) stated that keratin-based biomaterials promote nerve repair, hemostasis and wound

healing, highlighting their potential in tissue regeneration applications.

These biomaterials have cell-binding motifs like leucine-aspartic acid-valine and glutamic acid-aspartic acid-serine. These binding residues are responsible for secondary cellular attachment (Rouse and Van Dyke 2010). The various applications of keratin are described in Fig. 5.

Biomedical application

Keratin-based materials exhibit great mechanical durability, are extremely biocompatible and are easily biodegradable. These distinct properties have caused a revolution in the field of modern biomaterials. These materials are easily transformed into complex 3-D scaffolds, sponges, films and hydrogels for various biomedical applications (Feroz et al. 2020).

Keratin-based hydrogels have shown promising results as biomaterials in various biomedical applications. Keratin hydrogel (purity 9%) has shown the ability to reduce burn progression and promote skin regeneration. A concentration of 15% has proven to be effective in nerve regeneration and recovery (Chen et al. 2020). A mixture of 5% keratin hydrogel with 5% polyvinyl alcohol exhibits a wound healing process in vivo (Chaitanya Reddy et al. 2021). Keratin polymers have been used for developing scaffolds for dental tissue engineering; hydrogels with a concentration of 20% keratin and 3% glycerol have enhanced odontoblast cell behaviour and have shown promising results in pulp-dentine regeneration (Zafar et al. 2020). The cross-linked disulfide hydrogels are excellent candidates for drug release and delivery. The keratin allyl thioether hydrogel has controlled degradation and is a viable matrix for encapsulation and cell delivery (Chen and Liu 2016).

Keratin films are used to produce new biodegradable and biocompatible materials for wound repair and tissue engineering. They promote cellular adhesion and represent a novel approach to wound management. Films prepared with 10% of keratin and gelatin in 1 ml ethylene glycol and glutaraldehyde (0.35 ml) exhibit remarkable mechanical and water absorption properties and are thus used as wound dressing materials (Radoor et al. 2020). Keratin and chitosan films prepared in 20% glycerol are used as materials for contact lenses. Keratin films are brittle and fragile in nature; adding a plasticiser like glycerol or sorbitol makes them durable (Irina Barzic et al. 1964). Keratin films are excellent alternatives for ocular surface reconstruction as they possess the ability to transmit light effectively and have great mechanical strength (Fig. 6).

Fig. 5 Applications of keratin

Keratin fibres formed with polymers made particularly of poly (L-lactic acid)/poly (hydroxybutyrate-co-hydroxyvalerate) are used in wound healing materials (Azimi et al. 2020). These polymeric nanofibers play a great role in tissue engineering, drug delivery, and wound healing due to their ability to restore the natural extracellular matrix function. Keratin fibres fabricated from electrospinning polycaprolactone with keratin in a ratio of 7:3 are used in bone tissue engineering (Cho et al. 2020). Electrospinning has been used to prepare such nanofibers because of its reliability and effectiveness. Keratin-polyamide 6 composites prepared with 15% w/w formic acid are widely used in bio-medical devices and as adsorbents for purifying water (Yadav and Purwar 2021).

Keratinous scaffolds prepared from keratin-chitosan composites (2:1, v/v) are used in antimicrobial treatments and are good candidates for cell seeding (Sadeghi et al. 2020). Polylactic acid/chitosan-keratin composites encourage stimulation and proliferation of osteoblasts and help in bone tissue regeneration (Chakravarty et al. 2020). The carboxymethyl/hydroxyapatite-keratin composites have demonstrated immense mechanical integrity and are employed for bone healing and drug release (Lago and Felisberti 2020). Due to their ability to polymerise and self-assemble, these bioactive scaffolds are able to successfully reinstate a variety of tissues.

Cosmetic application of keratin

The keratin hydrolysates are used in various cosmetic applications, such as hair and skin applications. The keratin peptides improve hair moisture and provide shine and softness to the hair. They have a hydrating effect on the skin and are used in skin and hair moisturisers (Barba et al. 2008). Keratin improves the mechanical and thermal properties of hair and is compatible with water, supporting the usage of its cosmetic products. Keratin peptides can reinforce the skin barrier function and reduce transepidermal moisture loss, keeping the skin firm and supple. Keratin hydrolysate acts as a humectant that binds water from the lower layers of the epidermis to the stratum corneum. Some studies have suggested that supplementing intercellular lipids of the stratum corneum can enhance the skin's functioning. Solubilised keratin proteins bond to the natural nail and strengthened the nail plate (Lusiana et al. 2011). Hydrolysed keratins in a concentration of 0.2% are used in mascaras and about 0.028% in bath soaps and detergents.

Keratin as biosorbents

Keratin biomaterials aid in eradicating heavy metals from water. These biomaterials operate through active polar sites on their surface to attract the charged metal ions via the physical and chemical surficial mechanism. Keratin extracted from three different sources like chicken feathers, human hair and animal horns are used as biosorbents. Keratin from chicken feathers is used to adsorb Cd, Ni, Cr, Zn and Ar metal ions. Keratin extracted from wool and feather is used to adsorb metals Pb (II) and Pb (I), respectively.

Keratin as biofertilisers

Keratinous wastes are used as organic fertilisers due to the presence of carbon and nitrogen. Keratin is a reliable source of nitrogen used to prepare fertilisers (Petek and Marinšek Logar 2020). Feather waste is a good source of biofertiliser

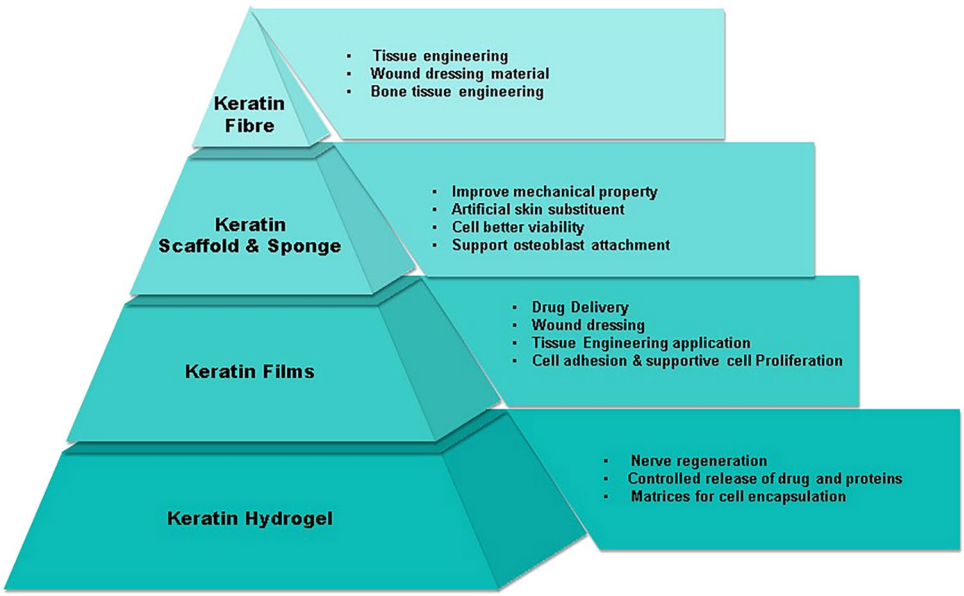

Fig. 6 Core biomedical application of keratin

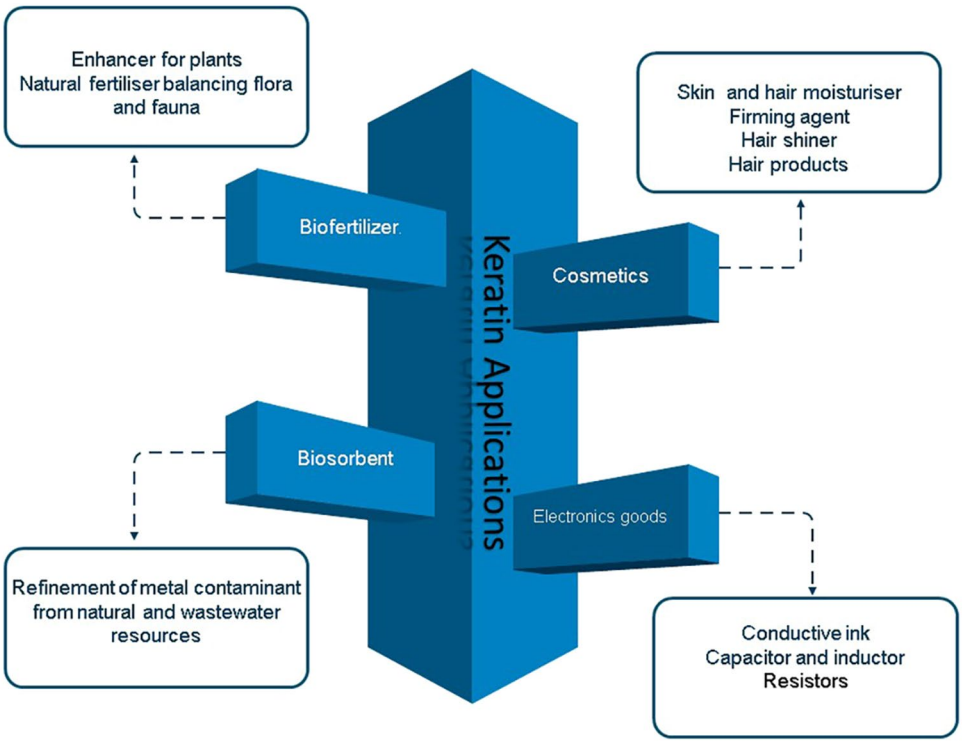

Fig. 7 Various applications of keratin

as it is rich in peptides, amino acids and minerals. The feather hydrolysate can restore contaminated soil and accelerate plant growth and has been found to be effective in the cultivation of crops.

Miscellaneous applications

Keratin extracted from human hair is used in construction materials and as plasters for house walls (Gupta 2014). Biodegradable materials obtained from keratin are used to construct electrical devices like resistors, capacitors and inductors. These applications are shown in Fig. 7.

Conclusion

Keratin represents one of the toughest biological materials and forms an effective protective integument in vertebrates. The research work done using keratin shows the acceptability and reliability in the pharmaceutical, cosmetic and biotech industries. This study's primary aim is to address various sources from where keratin can be extracted and converted into a more beneficial form. Various keratin-based biomaterials like hydrogels, films, fibres, sponges and scaffolds have been extensively investigated over the past few decades for their application in the field of biomedical sciences. These biomaterials have demonstrated excellent durability, biocompatibility and biodegradability. Extraction of keratin from biomasses derived from food industry by-products (slaughterhouse, dairy and poultry) is a challenging process hampered by the presence of disulphide bonds that bestow high resistance to chemical, enzymatic and thermal treatments. The economy of keratin is also a concern as the production is costly, which eventually leads to a higher price of keratin products. However, further research is required to find cost-effective and efficient methods of extraction.

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