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# Collagen Biopolymer in Textile Wet Processing

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Collagen is the most abundant protein in the animal kingdom and is a key component of the extracellular matrix (ECM). Collagen is produced from both natural and synthetic resources. Natural resources are the best resources. Collagen has attracted wide attention in several fields due to its abundance, low cost, and exciting physical and chemical properties, especially, biocompatibility and biodegradability. However, collagen suffers from weak physical and chemical characteristics (mechanical strength, thermostability and resistance to enzyme). As a result, collagen must be modified throughout the processing process. collagen is an eco-friendly resource that can be used to produce multifunctional, recyclable, biocompatible, and biodegradable materials that are ideal for new technologies in materials science, biomedicine, and environmental remediation.

**Keywords:** Collagen, Pre-treatment, Dyeing, Finishing.

## Introduction

Collagen is the most prevalent protein in animals and the main component of their bone and skin. It is one of the numerous extracellular Matrices. The semantic origin of the term "collagen" is originated from the Greek term "Kolla," which means glue.

It's a type of natural polymer with properties including good hydrophilicity, moisturizing, reproducibility, and biodegradability. [1-3]

*Collagen sources*

Collagen is produced from both natural and synthetic resources.

*Natural sources*

Collagen resources can be obtained from both animal and botanical sources. Bovine, porcine, human collagen and marine creatures are the most prevalent animal sources of collagen. Other landed animal sources include sternal cartilage from domestic birds such as chickens (broiler and laying hens), turkeys, quails, ducks, and geese; bovine skin, tendon, and bones from buffalos, lamb, equine, porcine, ovine, and rabbits; and bovine skin, tendon, and bones from buffalos, lamb, equine, porcine, ovine, and rabbits. [4-6]

Collagen derived from marine sources, such as scale fish and fish skin, has biochemical and biophysical characteristics that are similar to swine and bovine collagen. Thus, teleost and cartilaginous fish and/or marine invertebrates from freshwater and marine settings are viable resources. [4]

Although these sources are inexpensive and simple to get, long-term usage can be allergic and cause a variety of ailments. Another natural source that appears to be free of disease transmission is marine collagen. Collagenous biopolymers extracted from teleost fish, cartilaginous fish and marine invertebrates have physicochemical and spectroscopic characteristics close to those from mammals with some advantages:

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- A large supply of fishing and aquaculture by-products, primarily fish skin and scales
- Greater ontogenetic distance between fish and humans (low risk of disease transmission when compared to mammal collagen)
- absence of cultural and religious barriers
- more straightforward extraction procedures (many times supported by new technology, such as sonication)
- glycine and alanine content, acceptable arginine, and glutamic acid content, good flexibility, bioresorbability, and glycine and alanine content
- absent (fish) or almost insignificant (marine invertebrates) toxicity
- minimal inflammatory response
- low melting point and viscosity
- good homeostatic properties. [4, 5, 7]

*Synthetic collagen sources*

Collagen supplies are increased to avoid immunological issues caused by natural collagen. KOD, a commercially available substance, is one of these sources. It's a synthetic protein of 36 amino acids that self-assembles into triple-helix nanofibers and hydrogels.

Another synthetic source for collagen has been created using recombinant technology to deliver high-quality, animal-derived, contaminant-free collagens. Mammalian cells, insect cell cultures, yeast, and plant cell cultures are all used to make it. The downsides of recombinant technologies are their high cost, limited yield, and the lack of cofactors or enzymes in the systems. Animal collagen is the gold standard for usage in both scientific and therapeutic settings for these reasons. advantages and limitations of collagen from different sources are listed in Table 1. [5, 8]

*Collagen's superfamily and structure*

Collagen is a triple-helix protein made up of three polypeptide chains. The polypeptide chains are made up of two identical (α1) chains and a second (α2) chain with a tiny chemical variation. [9]

All collagens are right-handed triple helices comprised of three left-handed peptide chains, linked by hydrogen bonds, each containing about 1000 amino acids. Peptide chains consist of regularly repeating sequences, while every third amino acid is glycine, the smallest amino acid, and many of the remaining amino acids are proline or hydroxyproline. All glycine residues are positioned in the central axis, and structurally larger amino acids are situated in the outer positions of the triple helix. [5, 10, 11]

Collagens have been discovered in 29 different varieties that are classified into different superfamilies on their structure and function (see Table 2). [2, 12-14] Collagen has physicochemical, densitometric, and spectroscopic characteristics that change depending on the source, such as intra-polypeptide and interpolypeptide molecular organisation, stability, and elasticity. [5]

To present, 40 vertebrate collagen genes have been found, resulting in the formation of 29 different homo- and/or heterotrimeric molecules. The type is denoted by Roman numbers, while the chains, bands, and higher molecular weight components are denoted by Greek letters. [15] collagen subfamily and types are listed in Table 2. Some chemical structures of collagen are presented in Fig. 1. [16]

**TABLE 1. Comparison of advantages and limitations of collagen from different sources.**

| Source | advantages | limitations |
|---|---|---|
| mammalian and marine tissue | High yield | • Interspecies disease transmissions<br>• Restrictions based on religion |
| Recombinant collagen is produced using genetically engineered microorganisms, animals, and plants | No batch-to-batch variation | • Low yield<br>• Low thermal stability<br>• Lack native post-translational modification mechanism |
| Synthetic collagen formed with collagen-mimicking sequences (Gly–X–Y) | Tailorable biofunctionality | • Lacking self-assembling capabilities |

**TABLE 2. collagen subfamily and types.**

| Subfamily | Collagen type | chains |
|---|---|---|
| fibrillar collagens | I (Heterotrimer) | [α1(I)]2 α 2(I)] |
| | I (Homotrimer) | $[\alpha\ 1(I)]_3$ |
| | II | $[\alpha\ 1(II)]_3$ |
| | III | $[\alpha\ 1(III)]_3$ |
| | V | [α 1(V)]2 α 2(V)<br>[α 1(V) α 2(V)<br>α ٣(V)] [α ١(V)]$_3$ |
| | XI | [α1(XI)α 2(XI) α α3(XI)] |
| | XXIV | $[\alpha\ 1(XXIV)]_3$ |
| | XXVII | $[\alpha\ 1(XXVII)]_3$ |
| fibril associated and related collagens | IX | α ١(IX) α ٢(IX)α α٣(IX)] |
| | XII | $[\alpha\ 1(XII)]_3$ |
| | XIV | $[\alpha\ 1(XIV)]_3$ |
| | XVI | $[\alpha\ 1(XVI)]_3$ |
| | XIX | $[\alpha\ 1(XIX)]_3$ |
| | XX | $[\alpha\ 1(XX)]_3$ |
| | XXI | $[\alpha\ 1(XXI)]_3$ |
| | XXII | $[\alpha\ 1(XXII)]_3$ |
| Beaded filament-forming collagen | VI | [α1(VI)α2(VI) α α 3(VI)] |
| Basement membrane and associated Collagens | IV | [α 1(IV)2α2(IV)];α3(IV),<br>α4(IV),α5(IV), α 6(IV) |
| | VII | $[\alpha\ 1(VII)]_3$ |
| | XV | $[\alpha\ 1(XV)]_3$ |
| | XVIII | $[\alpha\ 1(XVIII)]_3$ |
| Short chain collagens and related proteins (hexagonal network collagens) | VIII | $[\alpha\ 1(VIII)]_2$ α ٢(VIII) |
| | X | $[\alpha\ 1(X)]_3$ |
| Transmembrane collagens and collagen-like proteins | XIII | $[\alpha\ 1(XIII)]_3$ |
| | XVII | $[\alpha\ 1\ (XVII)]_3$ |
| | XXIII | $[\alpha\ 1(XXIII)]_3$ |
| | XXV | $[\alpha\ 1(XXV)]_3$ |
| Other collagens and collagen-like proteins | XXVI | $[\alpha\ 1(XXVI)]_3$ |
| | XXVIII | $[\alpha\ 1(XXVIII)]_3$ |

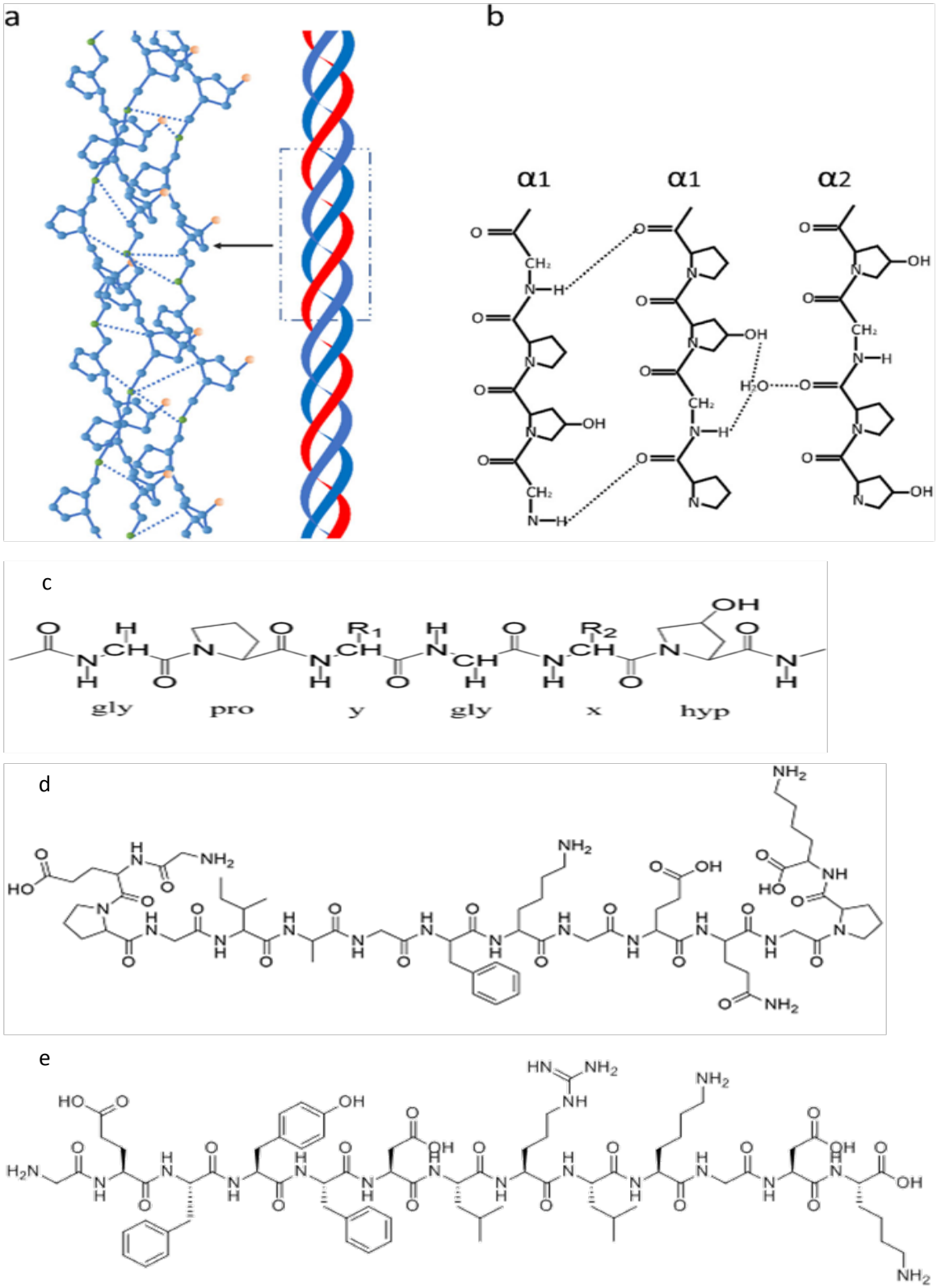


**Fig. 1. Some chemical structures of collagen from different sources.**

**(a) The triple helix of type I collagen, (b) hydrogen bonds of the collagen model, (c) type I-collagen, (d) type II-collagen and (e) type IV-collagen.**

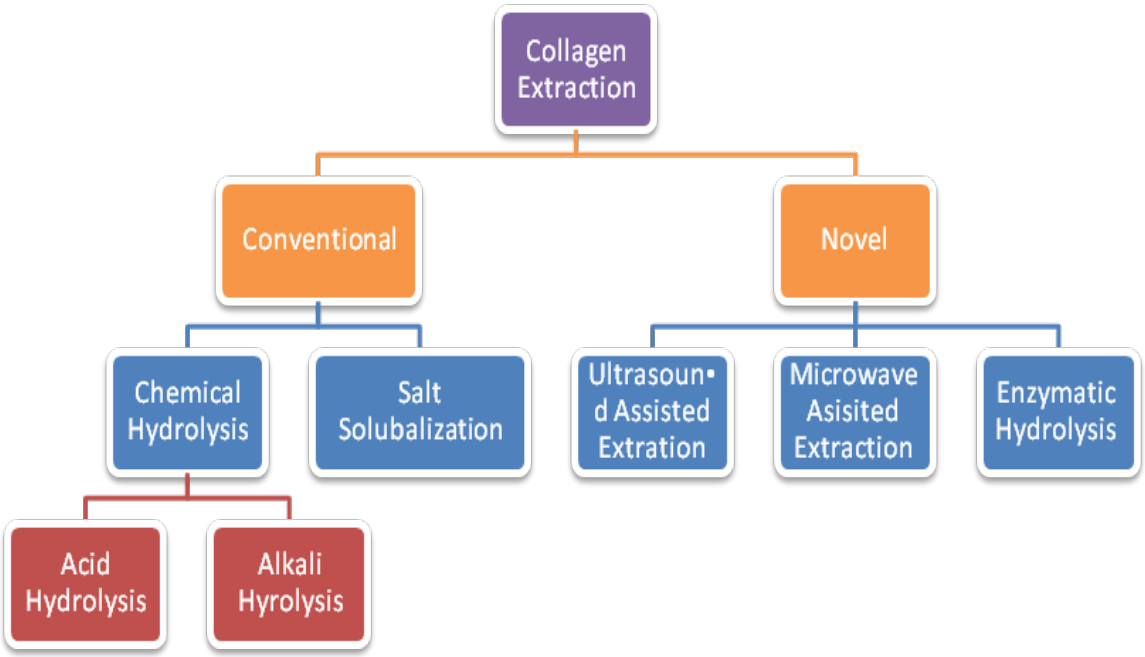


**Fig. 2. collagen extraction**

*Collagen extraction methods*

Collagen extraction techniques are classified into two categories: traditional and innovative. Both standard and new extraction methods may be further categorised into numerous categories based on the extraction process, such as chemical hydrolysis, enzymatic hydrolysis, ultrasound-assisted extraction, and pressured liquid extraction. (see Fig. 2) [17]

Collagen extraction protocols consist of four general steps: [4, 18, 19]

- raw material separation and size reduction (squares of ~ 1.5 ×1.5 cm).
- removal of non-collagenous components (sodium hydroxide (NaOH), hydrogen peroxide ($H_2O_2$), calcium hydroxide ($Ca(OH)_2$), or a combination of these).
- acid or enzymatic or ultrasound collagen extraction.
- purification by salt precipitation or chromatography methods.

*Conventional collagen extraction*

Chemical hydrolysis and salt solubilization are the most used conventional collagen extraction procedures. For collagen extraction, acid and alkali solubilization extraction techniques have been utilised, which are under the chemical hydrolysis category. For commercial collagen manufacturing, the chemical hydrolysis approach is preferred over the salt solubilization method.

*Salt Solubilization*

saline treatment for precipitation extraction utilising sodium chloride (NaCl) and/or guanidine hydrochloride (CH5N3.HCl), with one of the downsides of this procedure being a low extraction yield. [4]

*Chemical Hydrolysis*

The chemical hydrolysis process is divided into two categories: acid hydrolysis and alkali hydrolysis. The acid hydrolysis approach is widely utilised, and both organic and inorganic acids may break the bonds between collagen molecules and increase collagen fibril extraction.

Collagen molecules become more positively charged in acidic environments, and this positive charge helps their solubilization by producing repulsion among tropocollagen molecules.[17]

Organic acids, including i) acetic acid (CH3COOH) [20, 21], ii) citric acid (C6H8O7) [22], iii) tartaric acid (C4H6O6) and iv) chloroacetic acid and inorganic acids such as i) hydrochloric acid (HCl) and ii) formic acid (CH2O2), are used for the isolation of collagen. [4]

Organic acids, on the other hand, are more successful than inorganic acids at cleaving the crosslinks of collagen molecules, resulting in better collagen extractability. Acetic acid is the most often utilised organic acid for altering the electrostatic nature of collagen to improve its

solubility and extractability. [17]

Sodium and potassium hydroxide are the alkali solutions. As extractants, calcium oxide, calcium hydroxide, and sodium carbonate are also utilised. Furthermore, alkali has a high hydrolysis rate and can hydrolyze proteins by acting on collagen fibrils. However, due to the intense extraction conditions, amino acids such as serine, cysteine, histidine, and threonine may be damaged. [20, 21, 23]

*Novel collagen extraction methods:*

There are several novel methodologies for collagen extraction which address the limitations of conventional methods.

*Enzymatic extraction*

commercial enzymes (and/or pure enzymes) such as pepsin, papain, and/or collagenase enzymatic therapy. For this type of treatment, the extraction takes place in a medium containing organic acid (CH3COOH is the most used) with the addition of an enzyme (pepsin, for example [23, 24]). Enzymatic hydrolysis tends to eliminate the non-helical extremities, which enhances the solubility of collagen, making it the ideal approach for extracting collagen from teleost fish skin, scales, and swimming bladder residues. The likelihood of permanent denaturation of the collagen structure by enzymatic digestion is a drawback of this approach. [4]

The combination ultrasound-pepsin treatment yields more collagen and takes less time to process than the traditional pepsin isolation approach. Pepsin activity increases noticeably after ultrasonic irradiation with the experimental ultrasonic intensity. [23]

*Ultrasound extraction*

The industrial extraction system of collagen was developed using an ultrasound extraction system.

In the method: First, ice water and samples were put in a mixer and then run for approximately 3 min. When this operation was repeated 3 times, the scales were almost removed. Second, the fat was removed by stirring the sample in a mixer with a correspondingly 10-fold volume of 50% ethanol, and the residual muscle was removed with 0.6 M NaCl. Second, acetic acid solution (0.05 M) of a 100-fold amount to the weight of the sample was put in the sample tank, and then sufficiently cooled below 10oC, using the cooling system. A sample prepared in advance was slowly introduced into the sample tank and stirred. Then, the pump was operated to circulate the sample, and at the same time, ultrasonic devices were operated to generate ultrasonic waves. Ultrasonication was performed for 3 hours in this manner, and collagen was extracted by centrifugation. [25]

*Advantage of this method: [25, 26]*

It was possible to reduce the amount of acetic acid 10 times (0.5 to 0.05 M) used for collagen extraction and shorten the extraction time 8 times (24 to 3 hours) by utilizing this system.

Moreover, the purity of the collagen was comparable to the commercial one.

- In addition, the ultrasonic treatment highly reduced the costs for acetic acid, enzyme, and labour**.**
- Consequently, this ultrasonic treatment could be an environmentally friendly and effective method to extract collagen on an industrial scale.

*Microwave-Assisted Extraction*

The microwave-assisted extraction procedure is based on electromagnetic waves and cell structural disruption. Microwave radiation can reach the inside of proteins, freeing their structures from the cell-matrix and facilitating extraction. Microwave-assisted collagen extraction is frequently followed by enzyme hydrolysis because acid or enzyme-assisted hydrolysis can be accelerated by applying microwave power to finish collagen hydrolysis. [17]

*Modification of Collagen*

Collagen biomaterials have gotten a lot of interest in biological applications during the last several decades because of their great features such as minimal immunogenicity, biodegradability, biocompatibility, hydrophilicity, and ease of processing. However, collagen suffers from weak physical and chemical characteristics (mechanical strength, thermostability and resistance to enzyme). As a result, collagen must be modified throughout the processing process. [3]

Three types of polymerization techniques reinforce the collagen structure: (see **Fig. 3**) [15]

- physical (Temperature and UV light),
- chemical (Glutaraldehyde (GA), Chitosan, Dialdehyde starch, EDC-NHS and genipin)
- enzymatic cross-linking.
- Blending other biomaterials with collagen to create collagen-based composites might be a successful collagen modification approach. [3] Plasma treatment of collagen-containing polymer materials improves their biological compatibility and antibacterial capabilities while also increasing mechanical performance by modifying the material's internal structure. [27]

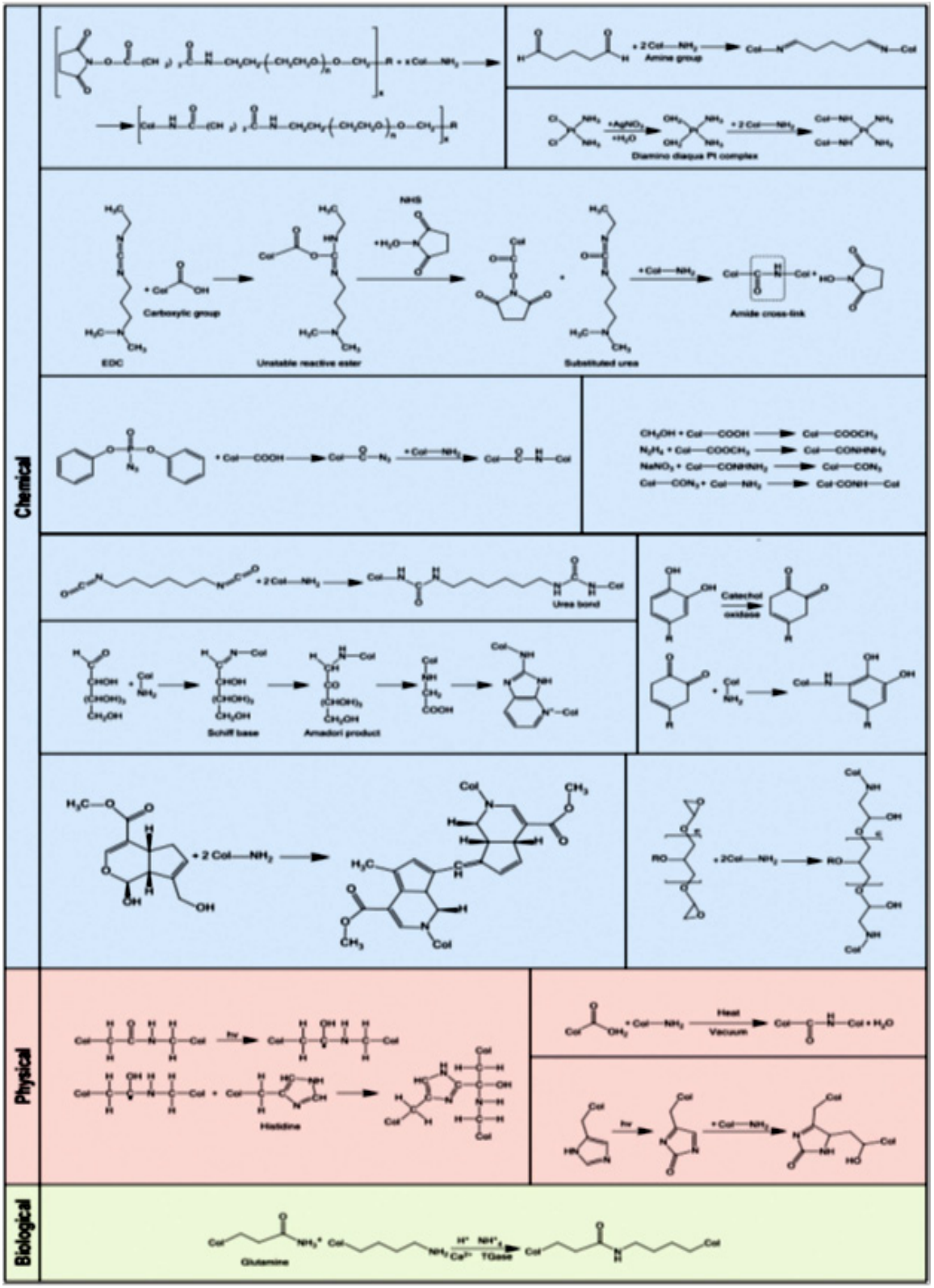


**Fig. 3. Indicative examples of chemical, physical, and biological exogenous crosslinks that have been utilized over the years to control the properties of collagen [15]**

In general, collagen's molecular bonding is exceedingly complex. Collagen's amino acid chains interact with various polymers, cross-linkers, nanoparticles (NPs), and other materials to generate products with exceptional qualities. Because of the wide range of linkages that collagen may form, it is an interesting possibility for the production of a vast array of materials for a wide range of uses. [9]

*Application of Collagen in Textile Industry*
*Modification of cotton with collagen*

By oxidising first and then crosslinking, collagen may be utilised to change the cotton fabric. The following crosslinking technique was found to be optimal: NaIO4 1.2 mg/ml; Collagen 1%; pH=4.0 for 1 hour; at 40°C. [28] In an aqueous acetic acid medium, the aldehyde groups on the glucose chains of oxidised cotton cellulose interacted with the amino groups of collagen, and the oxidised cellulose was crosslinked with collagen. The XPS spectra examination of the modified cotton fibre revealed that collagen had been crosslinked on the surface of the oxidised cotton fibre, resulting in a change in performance and a drop in breaking strength. The mechanical characteristics of collagen-modified cotton fibre have been enhanced. [28, 29]

*Effect of Modified Cotton with Collagen In Dyeing:*

Dyeing methods with acid dyes and reactive dyes are effective in the characterization of the modification effect collagen modified cotton. the K/S value with acid dyes was significantly improved on collagen modified cotton and the K/S value with reactive dyes was increased. [29, 30]

*Sizing and fire retardant treatment of cotton with collagen*

Cotton yarn is sized in the weaving industry to consistently feed the threads through the mechanics of weaving machines, decrease breakage, and enhance the weaving process. Sizing is only required during weaving, after which the sizing ingredients are removed from the cloth. [21]

For sizing cotton weaving yarns, instead of starch and polyvinyl alcohol, collagen of animal skins was proposed as a biodegradable natural substance. Collagen works best for sizing because some starch penetrates the walls of cellulose fibres during the sizing process when a starch solution is used. This makes it hard to eliminate starch from the woven fabric but sizing with a collagen solution enhances the morphology of the fibres and threads and is exclusively found on the surface of cotton fibres; no sizing agent is present in the interfiber region, making the fibres more elongated and homogeneous. [31]

The formation of new intermolecular connections, as well as advancements in fibre and thread microstructure and morphology, resulted in an improvement in the physical-mechanical properties of cotton threads sized with a collagen solution. The use of collagen expands the sizing process by allowing the size to be kept on the surface of the threads indefinitely, for example, to create fire-resistant textiles. [21, 31]

The influence of substances that do not ignite at a combustion temperature, decompose with the release of inert gas (nitrogen) and steam (water), making it difficult to ignite the material to be protected, and substances that form a dense film between air and material determines the protection mechanism (collagen). The addition of a nitrogen-containing, barely combustible polymer as a binder to the mixture, as well as grafting the composite flame retardant to the fibres of the textile material, improves protection efficiency. [21]

*Drug Delivery System with collagen*

A drug delivery system is a system that is used as a medium or carrier to provide a pharmacological substance to a patient to generate a therapeutic effect. Drug delivery systems (DDSs) play a key function in preventing growth factors and protein drug degradation. Collagen-based DDSs can be divided into a variety of forms, including scaffolds, hydrogels, granules, microcapsules, or microspheres, among others. Collagen scaffolds are the most prevalent type of collagen material for long-term release. [3]

In comparison to other biodegradable natural polymers (chitosan, elastin, glycosaminoglycan, silk fibroin, and so on) and synthetic polymers (polylactic acid (PLA), poly (lactic-co-glycolic acid) (PLGA), polyethene glycol (PEG), and so on), collagen is the most significant constitutive protein, which plays a critical role in the formation of the fundamental building block of connective tissues and its metabolism is associated. [3, 9]

The use of marine collagen, fish scale collagen peptides (FSCP) coupled with poly(3 hydroxybutyrate-co-4-hydroxybutyrate) (P(3HB-co-4HB)) by aminolysis to generate extremely hydrophilic scaffolds, has demonstrated a novel design of drug delivery system. The increased

hydrophilicity of scaffolds hastened wound healing and increased cell proliferation. The in vivo investigation revealed that P(3HB-co-4HB)/FSCP scaffold may increase fibroblast cell proliferation and expedite wound closure with a high disintegration rate, implying that it might be used for wound dressing and drug delivery systems. [32]

Natural temperature-sensitive systems exist and serve as ideal carriers. Collagen, for example, forms a triple helix with glycineproline-(hydroxyl) proline (Gly-Pro-Pro (Hyp)). The mechanism and chemistry of the inner groups can be used to classify thermosensitive polymers. Many hydrophobic medications, such as paclitaxel, are soluble in these polymers, and they make an effective formulation for weakly water-soluble pharmaceuticals. [33]

*Removal of water pollutants with collagen*

Synthetic dyes supplanted animal and plant dyes in the early twentieth century for use in colour items such as cloth, dyeing, printing, pharmaceuticals, paper manufacture, leather, edibles, and medicine, resulting in a vast volume of coloured effluent. [34] The public's concern over industrial pollution is driving calls for a cost-effective technology to remove industrial wastewater, which raises the risk of human cancer. There are now a few effective dye removal procedures in use; however, little has been done in the field of employing reusable biological material derived from the garbage.

Manal Shalaby et al. 2020. studied removal of dye by adsorption on various types of collagen was using soft, coarse and magnetic collagen nanocomposite. The magnetic collagen nanocomposite was synthesized by the coprecipitation method followed by the mixing of iron nanoparticles with collagen. Soft collagen, coarse collagen and magnetic collagen nanocomposite were proved to adsorb crystal violet dye at concentrations up to 1000 ppm. Uptake capacity was 92% at 100 ppm of CV while cytotoxicity was reduced to 15%. The ability of collagen and magnetic collagen nanocomposite to adsorb the dye and thus reduce the polluted water cytotoxicity, as well as accumulating under the action of the magnetic field was proved experimentally. [34]

Natural polymer-based hydrogels are gaining popularity since they are biodegradable, non-toxic, and environmentally friendly. Hydrogels are water-swellable polymer networks that can absorb and hold a substantial amount of water without disintegrating. Hydrogels are materials with a lot of potentials when it comes to wastewater treatment. They eliminate a wide range of water impurities since they are simple to remove after treatment. [35] To absorb or trap ionic dyes and heavy metal ions from wastewater, hydrogels should have a high concentration of ionic or nonionic functional groups in their structure, such as carboxylic acid, amine, hydroxyl, and sulfonic acid. As a result, natural polymers such as collagen are changed by grafting hydrophilic vinylic monomers onto their main chain. [36]

Savneet Kaur, Rajeev Jindal et. al., a green super adsorbent IPN hydrogel formed from (Gum copal alcohols-collagen) and acrylic acid comonomers was used to remove an organic pollutant like MB from the aqueous solutions. The adsorbent was found to remove 85.1 % of toxic MB dye. It was observed that the maximum dye removal was achieved for the initial dye concentration of 12 ppm at neutral Ph and an adsorbent dose of 300 mg. Pseudo first-order kinetic model was found to be the best fit for the experimental data. The IPN adsorbent also showed excellent regeneration efficiency for the three successive adsorption-desorption cycles making the dye removal process more economical. [35] ( see Fig. 4)

Collagen-based hydrogel nanocomposites, as adsorbent systems in wastewater treatment, were prepared by graft copolymerization of acrylamide and maleic anhydride onto hydrolyzed collagen using ammonium persulfate as an initiator and sodium montmorillonite as a nanoclay. To reduce pollution due to heavy metals and dyes resulting from industrial activities, hydrogel nanocomposites comprised of collagen, AAm, MAN and MMT were synthesized. The results indicated an excellent performance in the absorption of $Cd^{2+}$, $Pb^{2+}$ and dyes such as MG, CV. [36]

Another study used collagen and guar gum (ColGG) to create bio-based hydrogels for the removal of textile colours and metal ions. In the biopolymeric matrix, composite hydrogels with 1 wt percent MgMOF74, CaMOF74, and Zn(Atz)(Py) metal-organic frameworks were created. The hydrogels containing MgMOF74 and CaMOF74 improved the storage module of the matrix by 10% and 10%, respectively. Furthermore, MOFs reduced heat degradation and enhanced ColGG's water absorption capability. MOFs enhanced

adsorption performance for the removal of mordant brown and direct red from wastewaters. (see Fig. 5) The addition of MOFs improved adsorption performance more noticeably for the removal of $Cu^{2+}$ and $Zn^{2+}$ ions. The basicity of the organic linkers was critical in improving adsorption performance and physical qualities. Surprisingly, hydrogels neutralised the pH of wastewaters after adsorption. [37]

## Conclusion

Collagen is the most prevalent protein in animals and the main component of their bone and skin. It is one of the numerous extracellular Matrices. Collagen has sparked widespread interest in a variety of sectors because of its availability, low cost, and intriguing physical and chemical features, including biocompatibility and biodegradability. Collagen is used in different fields in the textile industry such as sizing of cotton, fire retardant, improvement of dyeing the cotton with acid dye, drug delivery and removing dyes from wastewater.

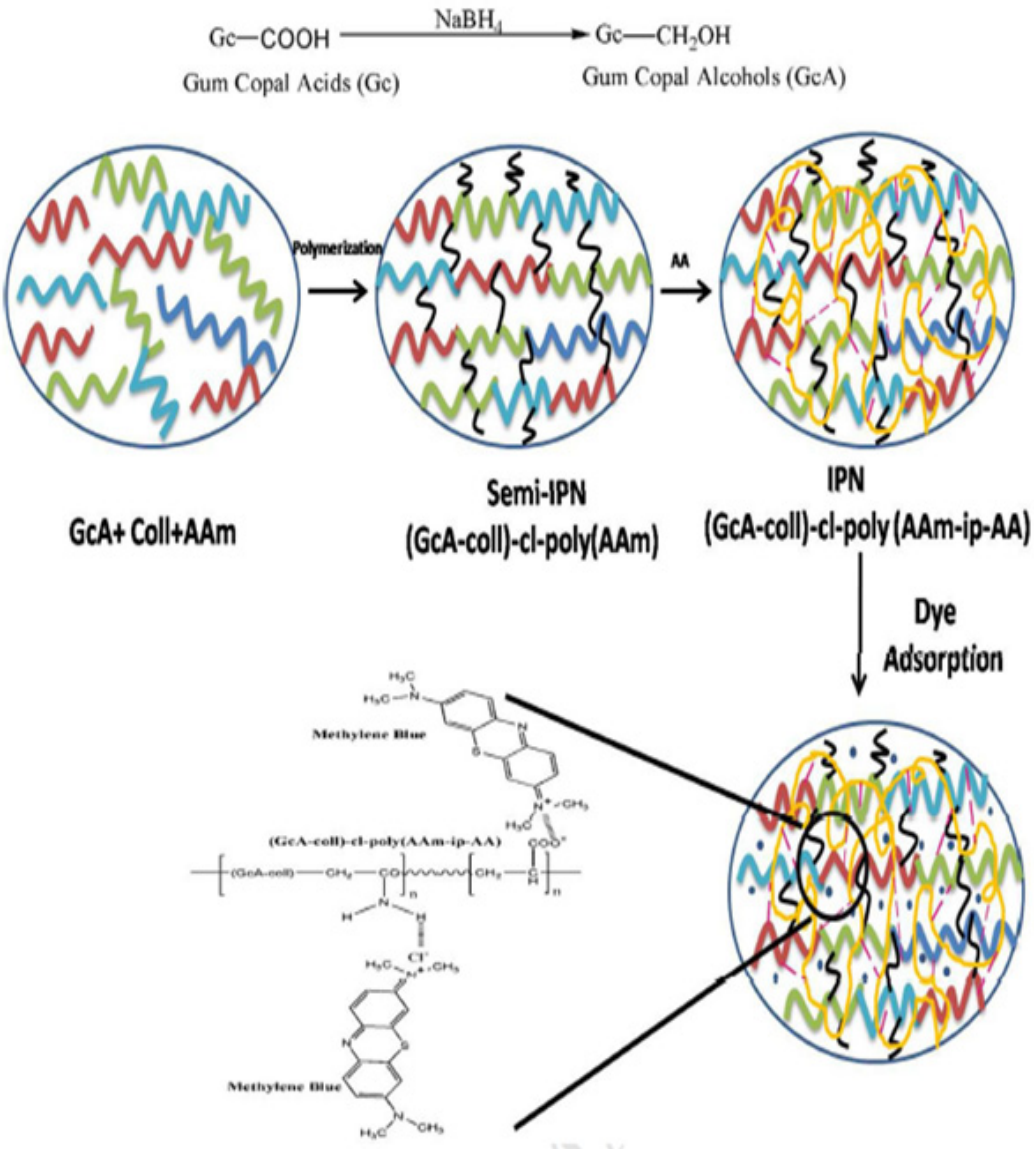


**Fig. 4. mechanism of removing MB from the aqueous solutions by a green super adsorbent IPN hydrogel formed from (Gum copal alcohols-collagen) and acrylic acid comonomers**

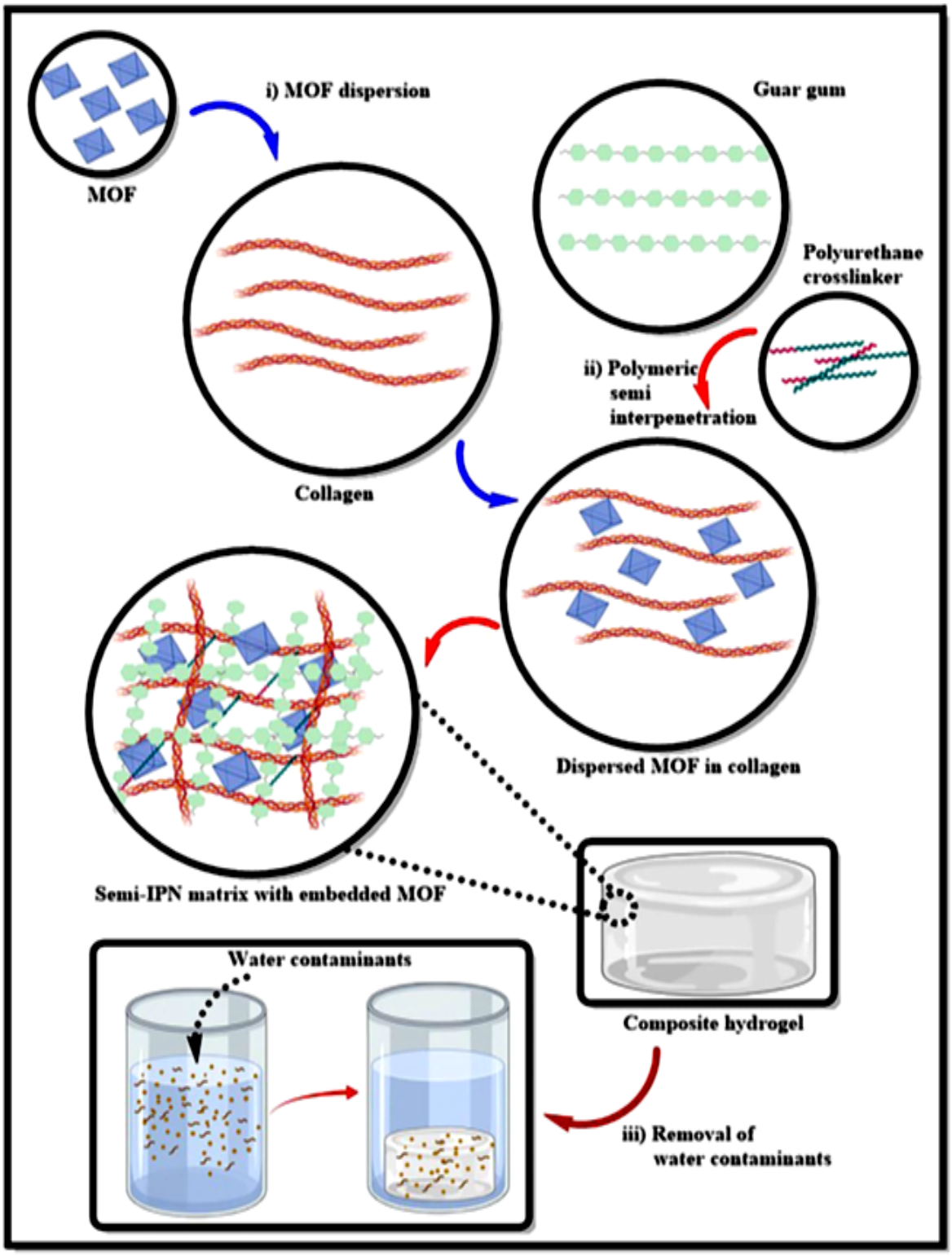


**Fig. 5. Schematic representation of the concept**

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# الكولاجين الحيوي في المعالجات الرطبة للمنسوجات

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الكولاجين هو البروتين الأكثر وفرة في المملكة الحيوانية وهو مكون رئيسي في المصفوفة خارج الخلية (ECM). يتم إنتاج الكولاجين من كل من الموارد الطبيعية والاصطناعية. الموارد الطبيعية هي أفضل الموارد. جذب الكولاجين اهتمامًا واسعًا في العديد من المجالات نظرًا لوفرته وتكلفته المنخفضة وخصائصه الفيزيائية والكيميائية المثيرة ، لا سيما التوافق الحيوي وقابلية التحلل البيولوجي. ومع ذلك ، يعاني الكولاجين من ضعف في الخصائص الفيزيائية والكيميائية (القوة الميكانيكية والثبات الحراري ومقاومة الإنزيم). نتيجة لذلك ، يجب تعديل الكولاجين طوال عملية المعالجة. الكولاجين هو مورد صديق للبيئة يمكن استخدامه لإنتاج مواد متعددة الوظائف ، وقابلة لإعادة التدوير ، ومتوافقة حيويًا ، وقابلة للتحلل الحيوي ، وهي مثالية للتقنيات الجديدة في علم المواد والطب الحيوي والمعالجة البيئية.

الكلمات الرئيسية: الكولاجين؛ المعالجات الأولية؛ الصباغة ، التجهيز