From lab to life: Understanding the Remarkable Properties & Practical Applications of Protein Biomaterials

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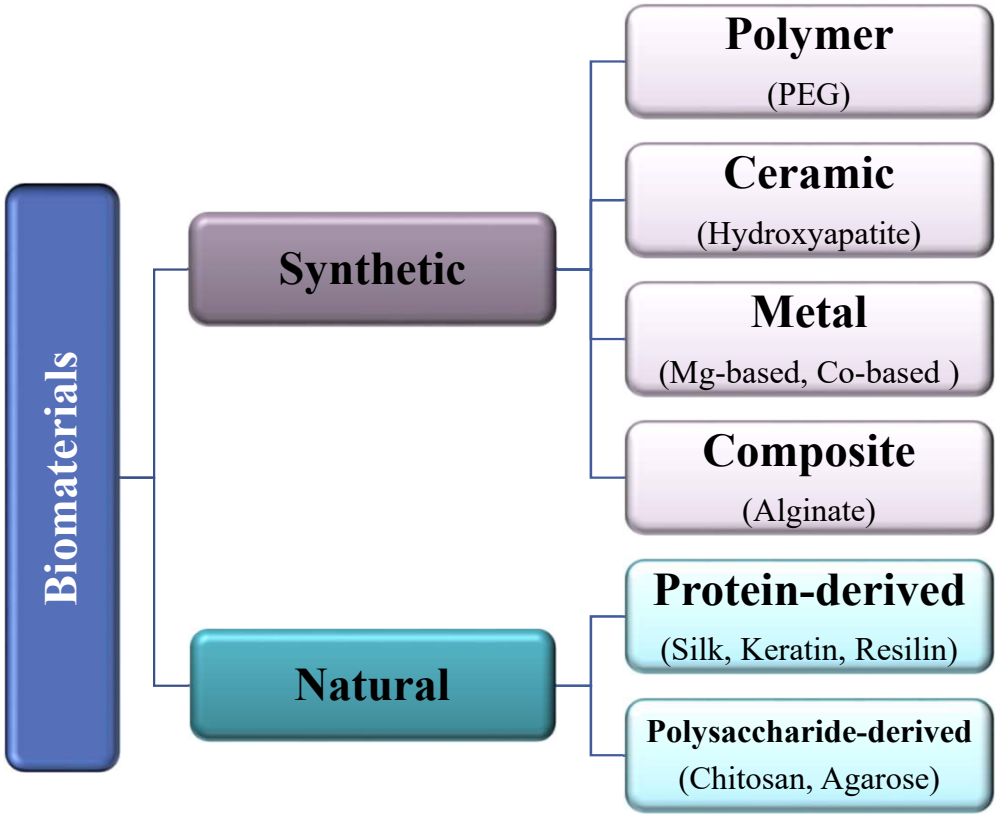
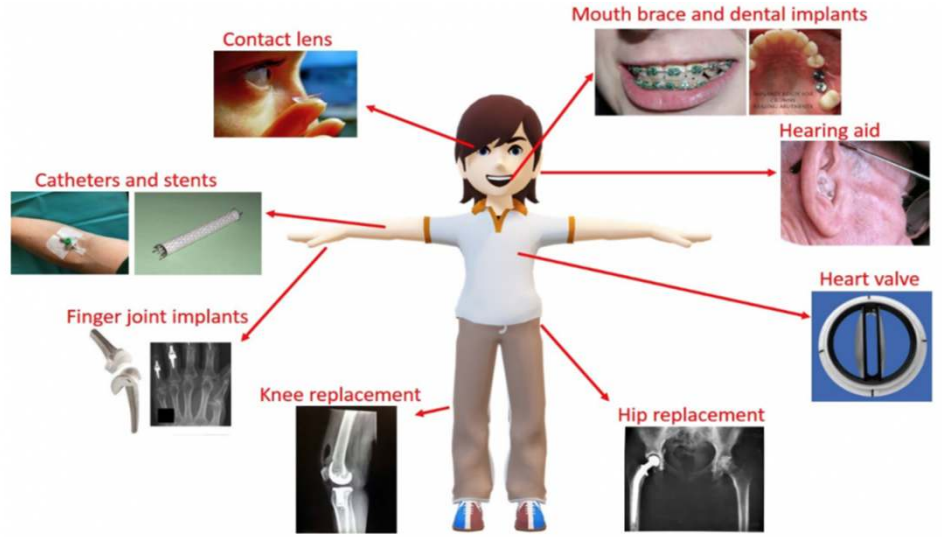
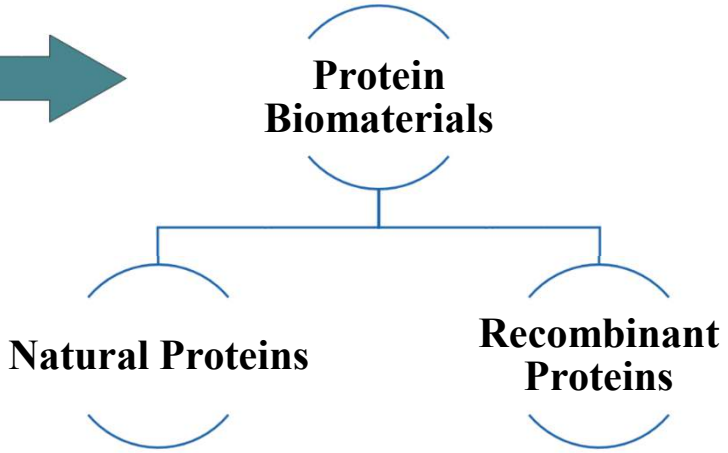
Classification of Biomaterials







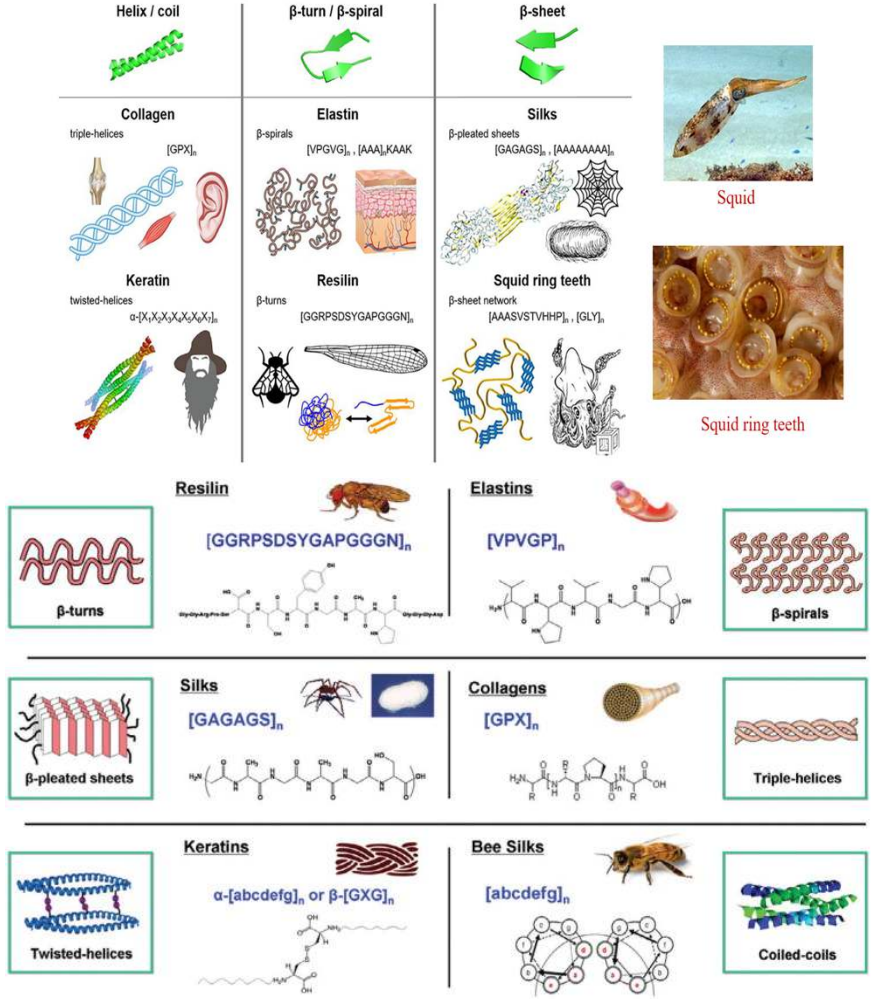
Global Biomaterials Market size is expected to be worth around USD 540.5 Billion by 2032 from USD 155.9 Billion in 2022.

Temenoff, J. S., & Mikos, A. G. (2008). Biomaterials: the intersection of biology and materials science

Protein Biomaterials

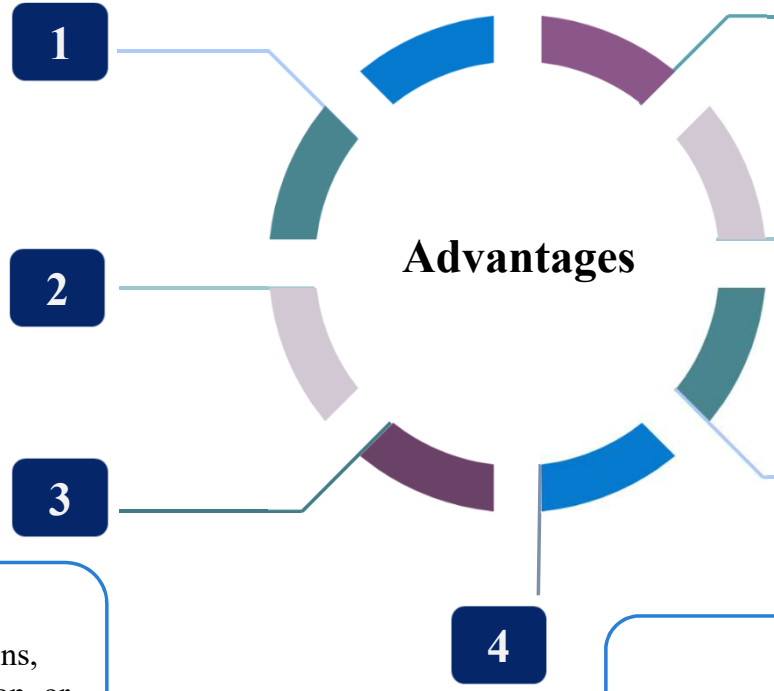
Proteins as Biomaterials

material	natural source	conserved repeat composition
silk	spiders, silkworm, etc.	$(GGXaa)_n$ Xaa = A, Y, L or Q
elastin	mammalian blood vessels, skin, etc.	$(VAPGVG)_n$
resilin	insects	$(AQTPSSQYGAP)_n$
collagen	mammalian tissues	$(GXaa\ Yaa)_n$ Xaa (often) = hydroxyproline Yaa (often) = P
keratin	reptilian scales, etc. mammalian wool, etc. avian feathers, etc.	α-keratin cysteine-rich α-helical repeats; β-keratin cysteine-rich β-sheet repeats



Abascal, N. C., & Regan, L. (2018). The past, present and future of protein-based materials. In Open Biology (Vol. 8, Issue 10). The Royal Society.

Protein Biomaterials: Advantages



Biocompatibility
Compatible with the human body

Biodegradability
Easily integrated and metabolized within living tissues

Functionality
Inherent biological functions, (enzyme activity, cell adhesion, or tissue regeneration) therapeutic or regenerative capabilities.

Versatility
By manipulating the amino acid sequence and structure of proteins, a wide range of biomaterials with different properties and functionalities can be create.

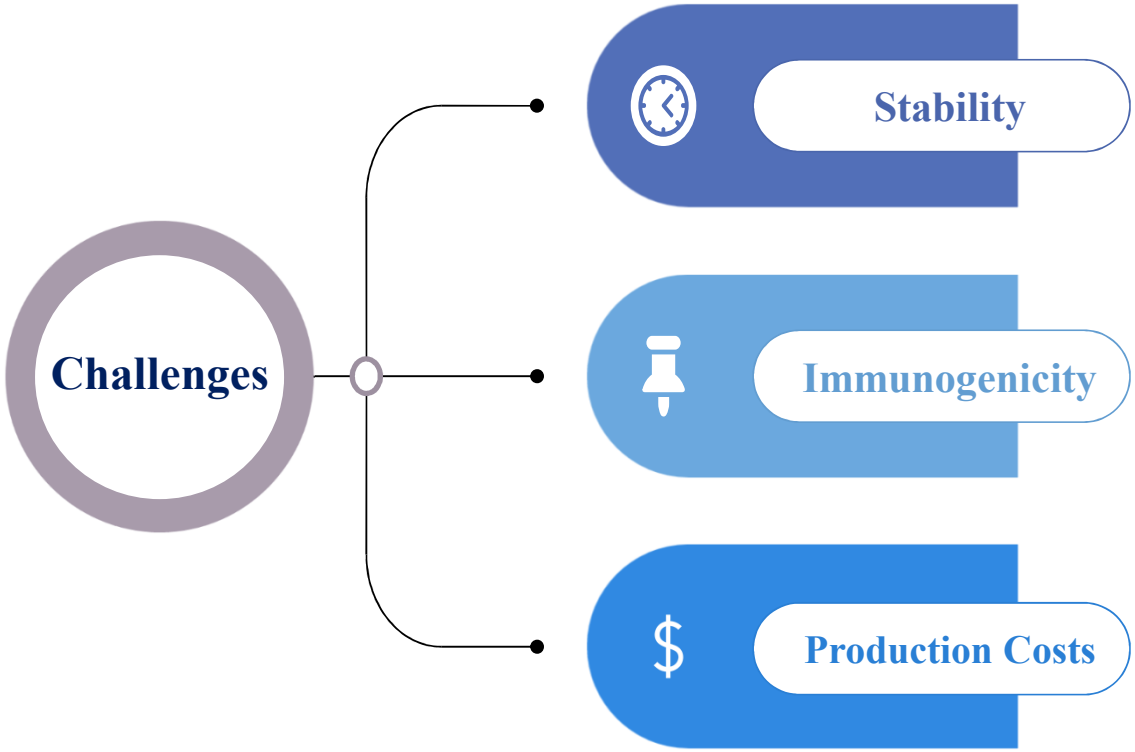
Cost-effectiveness
Compared to synthetic biomaterials.

Environmentally friendly
In Food science and packaging reduce plastic waste

Low immune response

Kianfar, E. (2021). Journal of Nanobiotechnology, 19(1), 159.

Protein Biomaterials: Challenges



- Proteins can be sensitive to environmental conditions, and maintaining their stability can be a challenge.
- Some proteins may trigger an immune response in the body, which can be a concern for certain applications.
- The production of certain protein biomaterials, especially those derived from recombinant sources, can be expensive.

Kumar, A., et al., (2020). International Journal of Molecular Sciences, 22(1), 138.

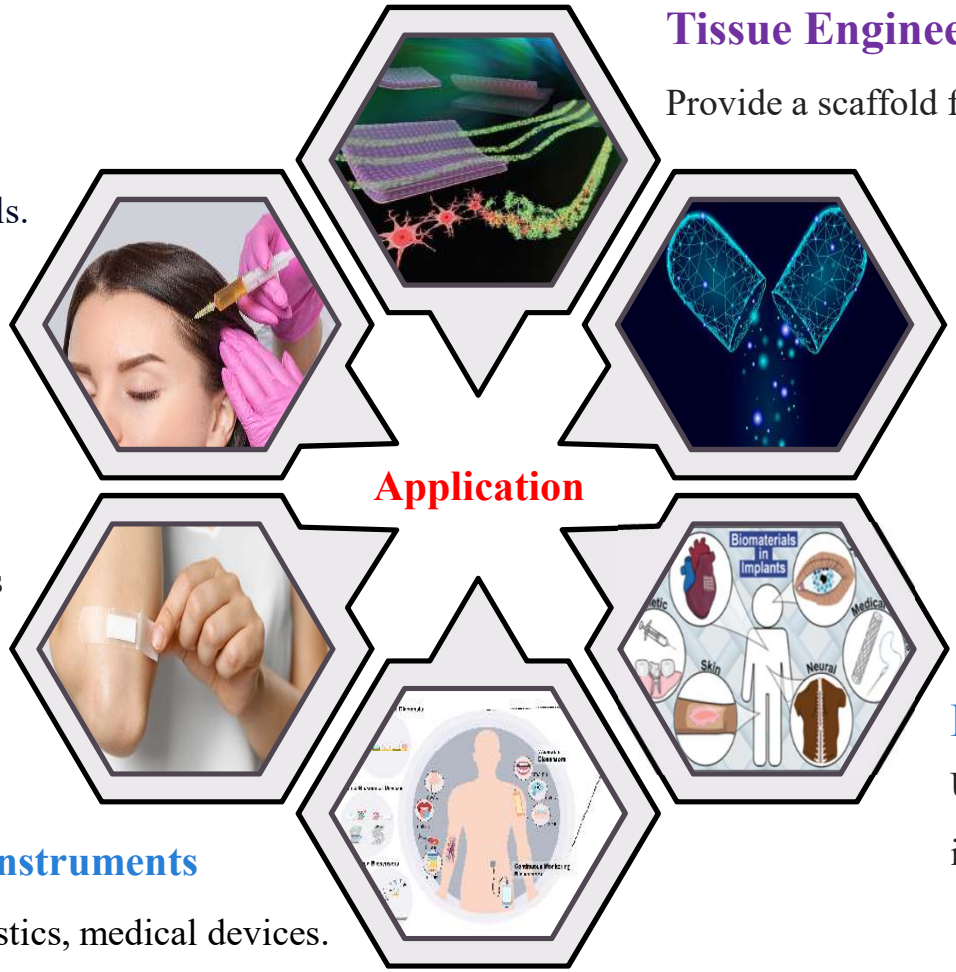
Protein Biomaterials: Application

Tissue Engineering

Provide a scaffold for cell growth and tissue regeneration.

Cosmetics

Applied in skin and hair care biomaterials.



Drug Delivery

Engineered to encapsulate drugs and release them in a controlled manner.

Wound Healing

Used in wound dressings and scaffolds to promote tissue repair.

Implants

Used in development of biocompatible implants and medical devices.

Biomedical Instruments

Used in diagnostics, medical devices.

Stie, M. B., et al., (2022). Journal of Controlled Release, 344, 12-25.

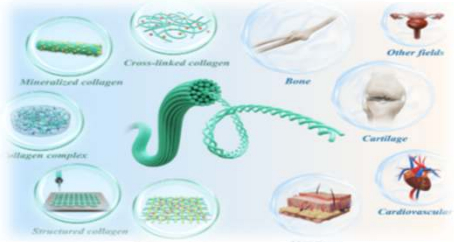
Protein Biomaterials: Natural proteins

Collagen

The main structural protein in the human body (skin, bone, and cartilage).

Processed into various forms (membranes, gels, and scaffolds).

Used in tissue engineering, drug delivery, and wound healing.



Silk

Natural protein biomaterial produced by silkworms cocoon and spiders.

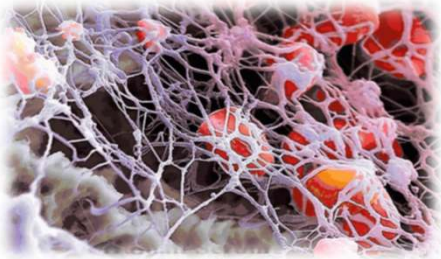
Has excellent mechanical properties high tensile strength and toughness.

Applied in tissue engineering, regenerative medicine, wound healing, drug delivery.

Fibrin

Involved in blood clotting. Isolated from plasma and used as a scaffold in tissue engineering and wound healing.

Fibrin-based biomaterials promote cell adhesion, migration, and tissue regeneration.



Fibrinogen

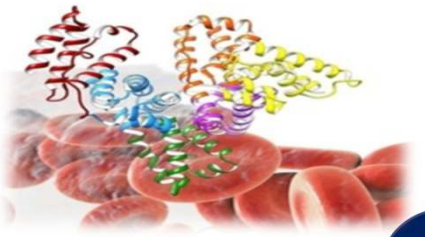
Involved in blood clotting
Convert into fibrin to form a scaffold for tissue engineering and wound healing.
Fibrinogen-based biomaterials promote cell adhesion, migration, tissue regeneration.

Albumin

Found in blood plasma.

Used for drug delivery, tissue engineering, and wound healing.

Has good biocompatibility and biodegradability.



Protein Biomaterials: Natural proteins (Cont.)

Keratin

Structural protein found in hair, nails, and skin.

Has excellent mechanical properties.

Explored for tissue engineering, wound healing, and drug delivery.

Elastin

Protein biomaterial provides elasticity and resilience to tissues.

Found in the skin, blood vessels, and lungs.

Used in tissue engineering and vascular grafts.

Soy

Plant-based protein biomaterial is biocompatible and biodegradable.

Used in tissue engineering, drug delivery, and wound healing.

Casein

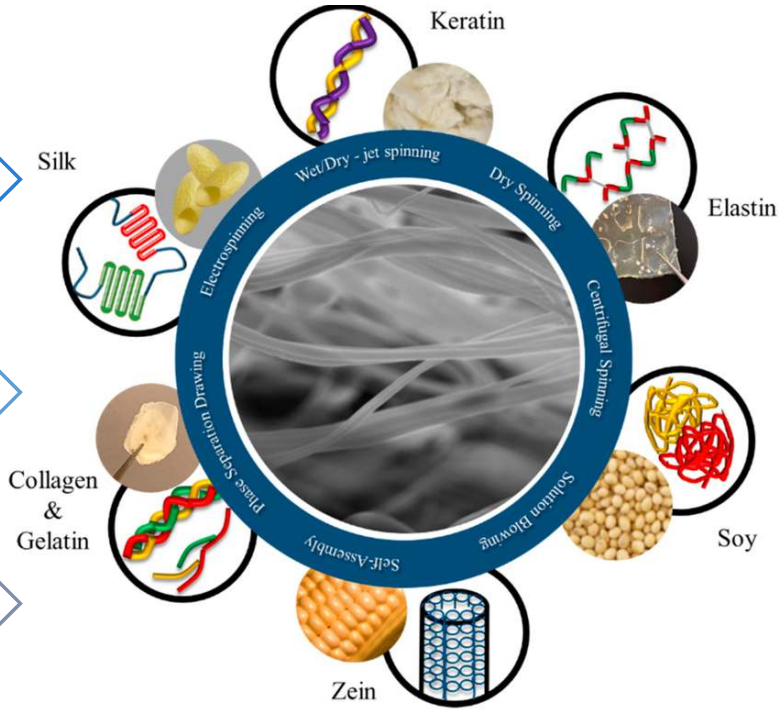
Found in milk.
It has good stability and biocompatibility.
Used in drug delivery, wound healing, and tissue engineering.

Gelatin

Derived from collagen.

Has biocompatibility, biodegradability, and easy processability.

Used in drug delivery, tissue engineering, and wound healing.



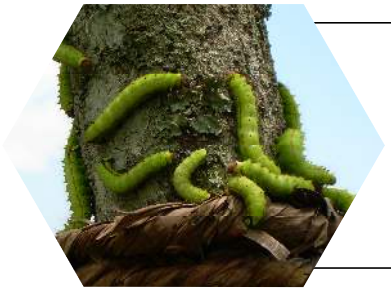
DeFrates, K. G., et al. (2018). *Nanomaterials*, *8*(7), 457.

Silk Fibroin

Silk Types

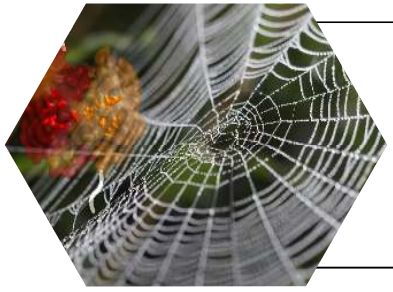
Mulberry Silk

Produced by silkworms fed on mulberry leaves
Common and widely used type of silk.



Wild Silk

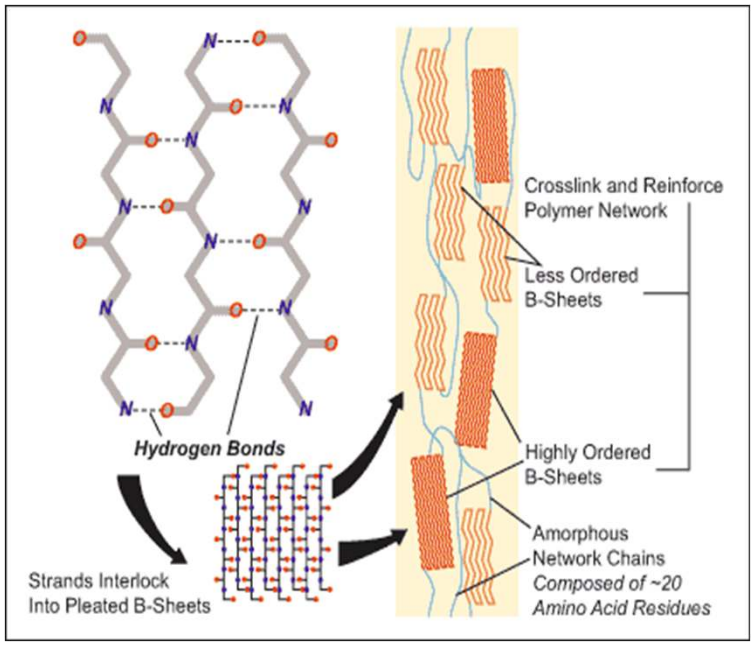
Produced by silkworms that feed on wild plants (different properties compared to mulberry silk).

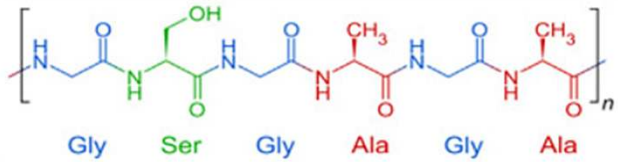


Spider silk

Produced by spiders and is known for its incredible strength and elasticity.

Silk Structure





Chemical structure of
Silk Fibroin

Nguyen, T. P., et al., (2019). *Polymers*, *11*(12), 1933.

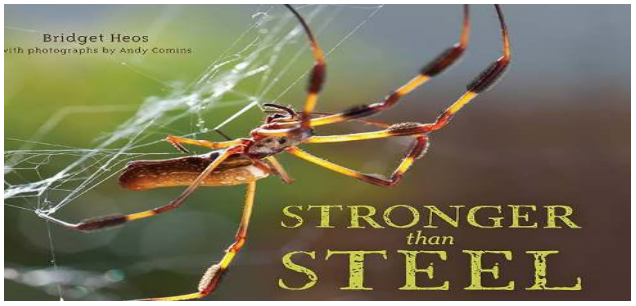
Spider Silk

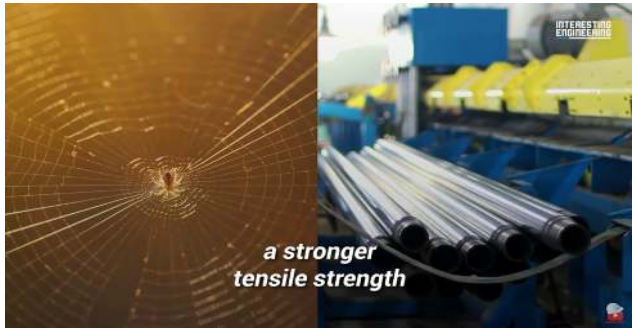
Natural spider silk is a protein biomaterial secreted by spiders through their silk glands.

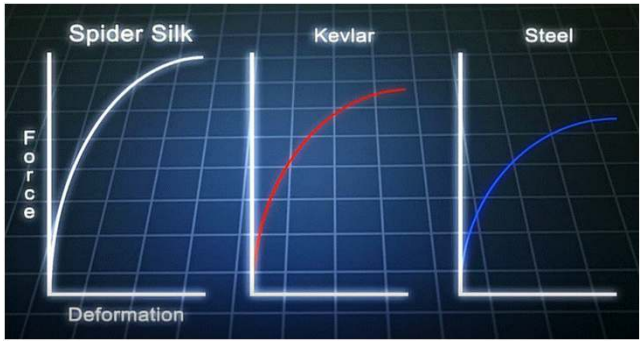
The ancient Greeks used spider silk to stop bleeding and heal wounds.

By the time of World War II, spider silk was used as a crosshair in the optical device of the sighting system of telescopes, guns.

The unit weight of spider line (Dragline silk) is three times stronger than that of aramid, five times stronger than that of steel, and two times more flexible than nylon.







Silk Protein Applications

Scaffolds for tissue engineering, drug delivery

Medical Applications

Textiles and Apparel

Clothing: softness, smooth texture, luxurious.
Sportswear: keep the body cool and dry.

For wound dressings due to their biocompatibility and potential to support the healing process

Wound Healing

Biodegradable Materials

Biodegradable Plastics alternative to traditional petroleum-based plastics.

Edible coatings for food products, provide a protective layer extend shelf life and maintain product quality

Food Industry

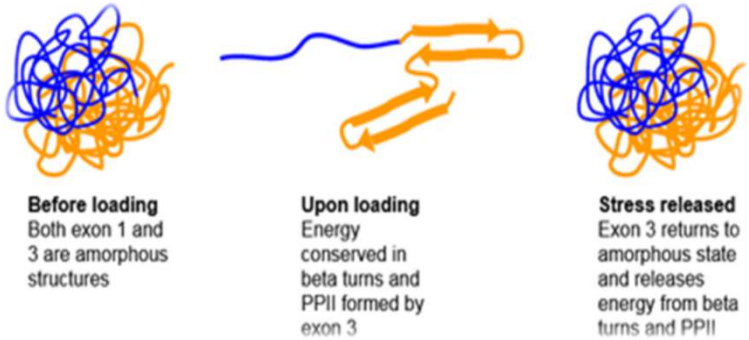
Cosmetics and Personal Care

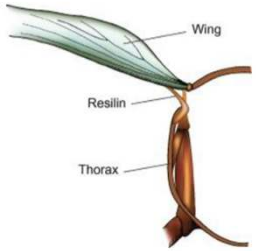
Moisturizing properties help improve the texture and feel of skincare and haircare formulations.

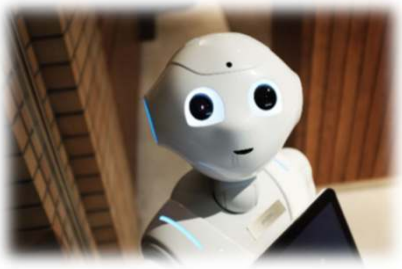
Liu, J., et al., (2022). Materials Advances, 3(5), 2291-2308.

Resilin

- Composed of proteins with a high content of the **proline**, provide elastic properties.
- Found in the cuticle of arthropods, which includes insects, arachnids, and crustaceans. enabling efficient and rapid movements (mechanism of fleas and grasshoppers).
- Exceptionally **elastic**, allowing it to stretch and then quickly return to its original shape.
- Use in structures like joints and tendons. Enables insects to perform rapid and powerful movements like jumping.
- Scientist develop synthetic materials with similar elasticity in robotics and biomechanics.





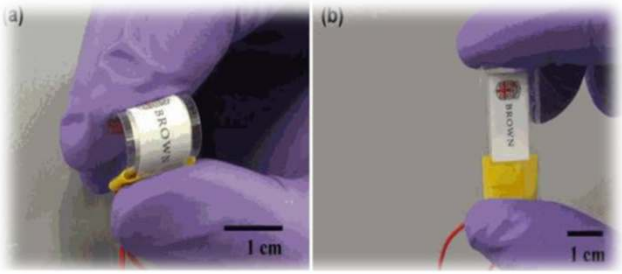


Lyons, R. E., et al., (2011). Insect biochemistry and molecular biology, 41(11), 881-890.

Resilin Applications

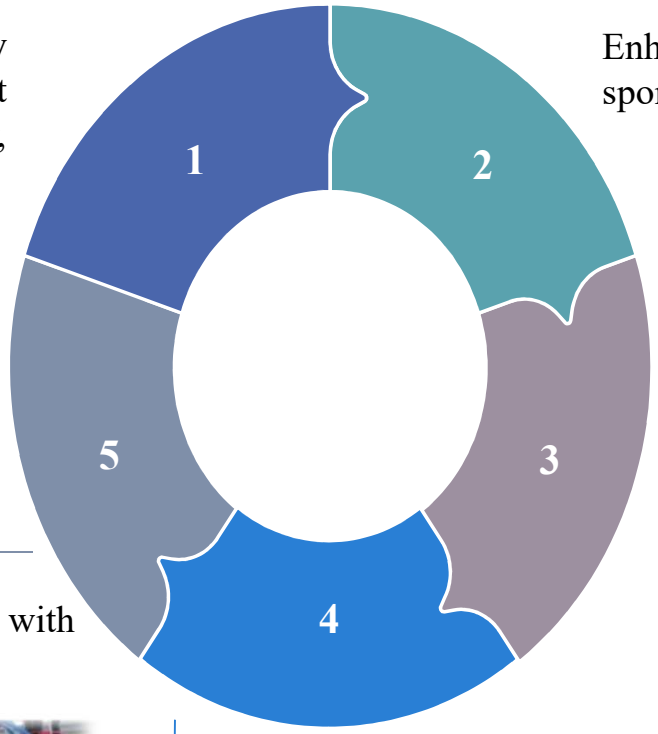
Energy Storage

Used in development of flexible energy harvesters that can efficiently convert mechanical energy into electrical energy, particularly in wearable devices.



Soft Robotics

Providing artificial muscles and actuators with enhanced flexibility and resilience



Medical Devices

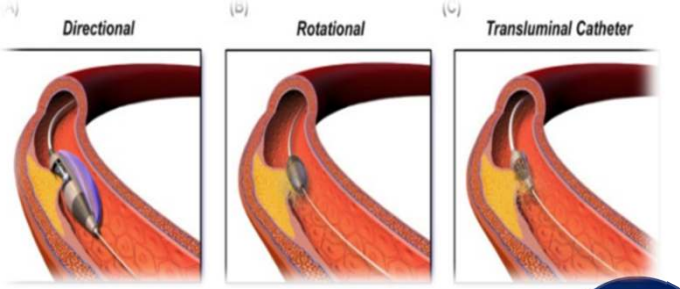
Used in catheters and stents, providing flexibility and durability for medical devices navigate through the body.

Textiles and Clothing

Enhance comfort and flexibility, particularly in sportswear or other garments that require elasticity.

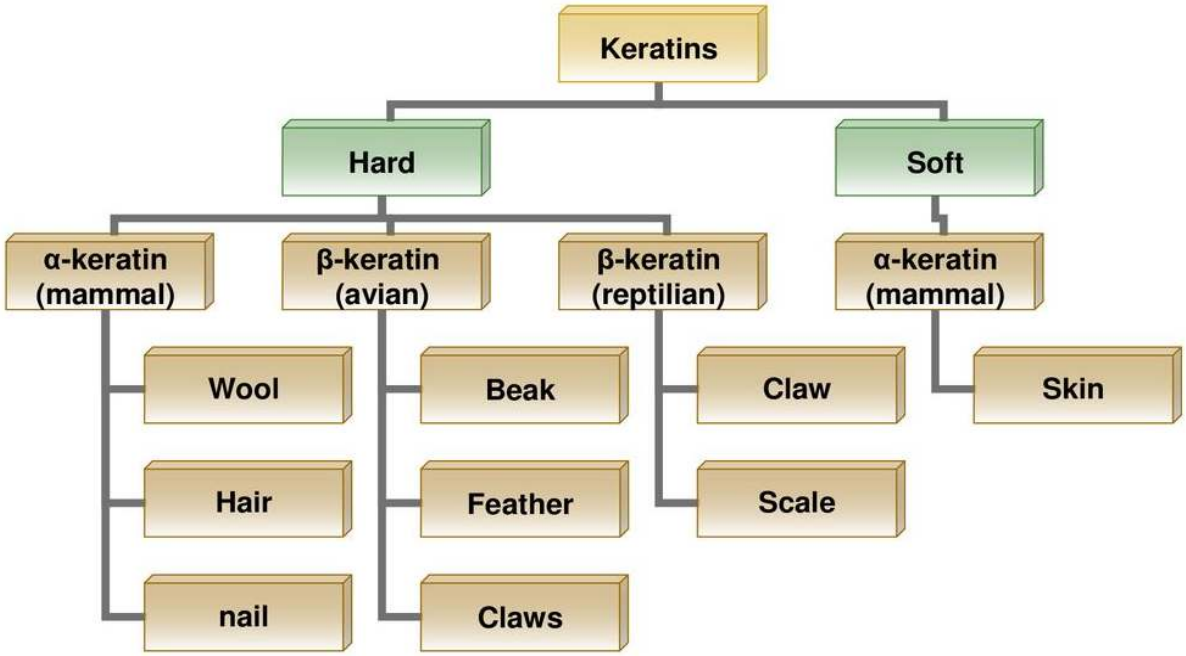
Biomedical Engineering

Create flexible scaffolds in Tissue Engineering mimic mechanical properties of natural tissues.



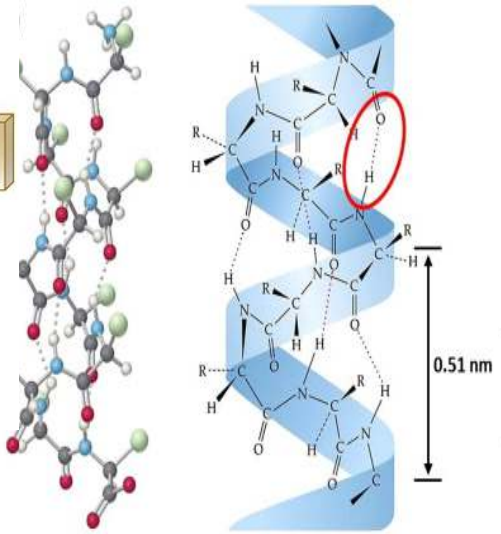
Keratins

Keratin is a tough and insoluble protein that provides strength and resilience to various biological structures

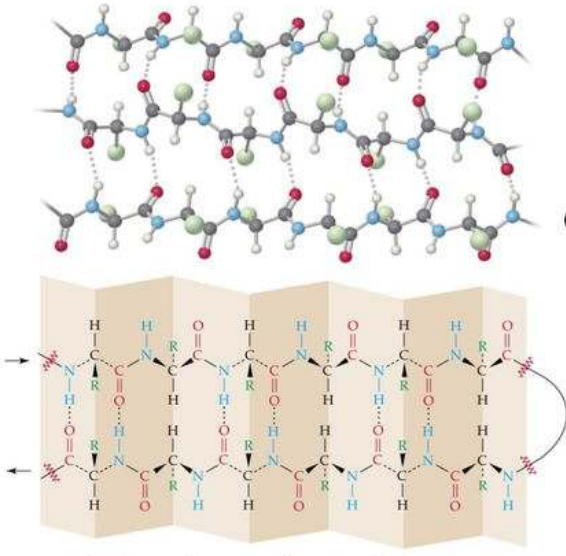


α-Keratin

β-Keratin



α-Helix



β-Sheet

R.D.B Fraser, T.P. Macrae, The mechanical properties of Biological Materials

Keratin Application

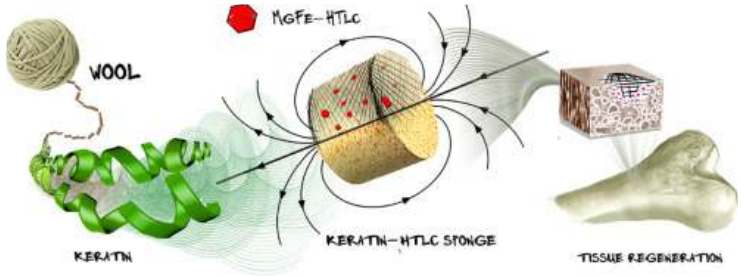
1-Cosmetics and Personal Care

- **Hair Care Products**
  Shampoos, conditioners, and treatments.
  Strengthen hair, reduce frizz, enhance shine.
- **Nail Care**
- Used in nail treatments and strengtheners to promote healthier nails.

2-Medical and Biomedical Applications

- Wound dressings due to their biocompatibility and potential to aid in tissue regeneration.

3-Tissue Engineering



- **Scaffolds for Tissue Regeneration**
- Used as a component in scaffolds providing a supportive structure for cell growth and tissue regeneration.

Ranjit, E. et al., (2022). Journal of Science: Advanced Materials and Devices, 7(1), 100398.

Keratin Application (Cont.)

4-Agriculture

- **Fertilizer Coatings**

  Keratin-based coatings applied to fertilizers to control the release of nutrients, improving the efficiency of nutrient uptake by plants.

5-Textiles and Apparel

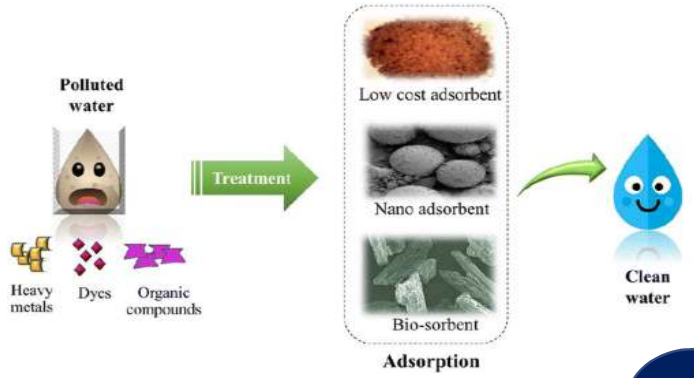
- **Fabric Finishing**

  Keratin treatments finish textiles, improving the feel and texture of fabrics.

6-Environmental Remediation

- **Wastewater Treatment**

  Removing heavy metals from wastewater (adsorbent to capture and immobilize metal ions).



Rashid, R., et al., (2021), Environmental Science and Pollution Research, 28, 9050-9066.