AMINO ACID AND PROTEIN

Amino acids are the building blocks of proteins, which are essential macromolecules found in all living organisms.

Introduction of Amino Acid

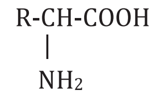
Amino acids are compounds that possess both an amino group and a carboxyl group within their molecular structure. They represent a highly significant class of bifunctional compounds, as they serve as the fundamental constituents of proteins.

Although nature has revealed the existence of numerous amino acids, there are 20 particular ones that hold a special place due to their presence in proteins. This select group of amino acids is detailed in the table. The table provides common or trivial names for these amino acids. Additionally, it presents a convention in which each amino acid is represented by a three-letter code, offering a convenient abbreviation for use in designating the sequence of amino acids within peptides and proteins, subjects you will delve into further.

Every living cell consists of a multitude of diverse proteins. These proteins invariably contain elements such as carbon, hydrogen, oxygen, nitrogen, and sulfur. Some may also incorporate phosphorus, iodine, and traces of metals like iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn). Proteins are, without exception, polymers composed of α-amino acids. Upon partial hydrolysis, they yield peptides with varying molecular weights, and upon complete hydrolysis, they provide α-amino acids.

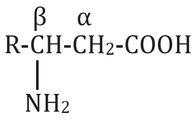
$$\text{Proteins} \xrightarrow{\text{Hydrolysis}} \text{Peptides } \alpha\text{-} \xrightarrow{\text{Hydrolysis}} \text{amino acids}$$

These organic compounds possess both an amino group and a carboxylic acid group. They are classified based on the position of the amino group within the molecule, and they are referred to as α, β, γ, and so forth amino acids.



$R\text{-}\underset{NH_2}{\underset{|}{CH}}\text{-}COOH$

α-amino acid

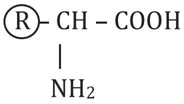


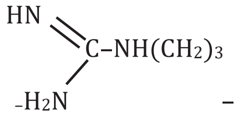
$R\text{-}\overset{\beta}{\underset{NH_2}{\underset{|}{CH}}}\text{-}\overset{\alpha}{CH_2}\text{-}COOH$

β-amino acid

There are approximately 20 amino acids, of which 10 are produced within our bodies and are categorized as non-essential amino acids (e.g., Gly, Ala, Glu, Asp, Pro, and Cys). The remaining amino acids that must be obtained through our diet are known as essential amino acids (e.g., Val, Leu, Ileu, Lys, and Phe).

Type of α-amino acids:

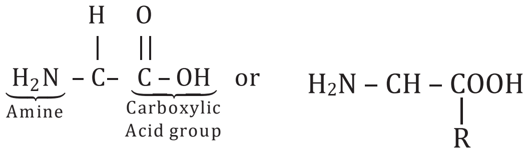
(1) Amino acids with non-polar side chain	**(2) Amino acids with polar and neutral side chain**
R – –  $\boxed{R}-\underset{NH_2}{\underset{\vert}{CH}}-COOH$ H – – Glycine CH_3– – Alanine $(CH_3)_2CH$– – Valine $(CH_3)_2CH–CH_2$ – leucine $(C_6H_5CH_2)$ – phenylalanine	R – CH_2OH – Serine $\underset{OH}{\underset{\vert}{CH}}$– CH_3– – Threonine HS–CH_2– – Cystine

(3) Amino acids with acidic side chain	**(4) Amino acid with basic side chain**
R – – CH_2 – COOH – Aspartic acid HOOC–CH_2–CH_2– – Glutamic acid	R – CH- | $H_2N–(CH_2)_4$– – OH lysine  HN C–NH(CH_2)$_3$ -H_2N – Arginine

Note: All α-amino acids except glycine have chiral C-atom and have (L) configuration normally.

Amino Acid: Building Blocks of Proteins

Amino acids serve as the fundamental units in the intricate molecular structure of proteins. Proteins, upon hydrolysis, yield a mixture of individual amino acids. Amino acids are bi-functional compounds that incorporate both an amino group and a carboxylic acid group and can be represented by the general formula:

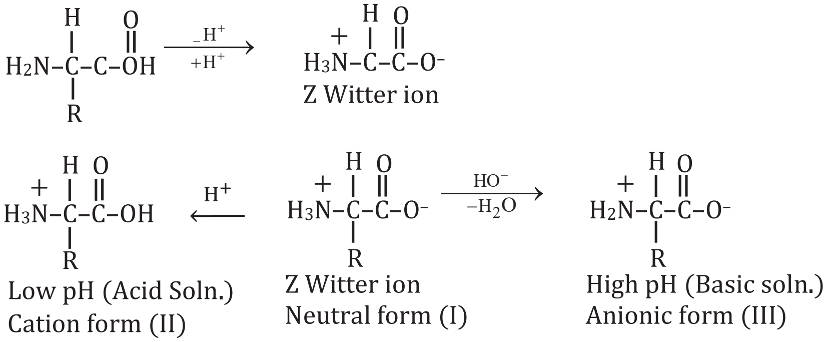


$$\underbrace{H_2N}_{\text{Amine}} - \overset{\overset{H}{|}}{C} - \underbrace{\overset{\overset{O}{||}}{C} - OH}_{\text{Carboxylic Acid group}} \quad \text{or} \quad H_2N - \underset{\underset{R}{|}}{CH} - COOH$$

Where, R = alkyl, aryl, or any other group.

Z Witter ion (Dipolar Nature of Amino acids)

In a solution containing neutral amino acids, the -COOH group donates a proton, while the -NH_2 group accepts one from the same molecule. This process leads to the formation of a dipolar ion, which is charged but maintains an overall electrically neutral state. This unique ion is referred to as a Zwitterion, derived from the German word "Zwei" (meaning "two") and "Ionen" (meaning "ions"). Consequently, amino acids exhibit amphoteric properties.



$$H_2N-\underset{\underset{R}{|}}{\overset{\overset{H}{|}}{C}}-\overset{\overset{O}{||}}{C}-OH \xrightarrow[+H^+]{-H^+} \overset{+}{H_3N}-\overset{\overset{H}{|}}{C}-\overset{\overset{O}{||}}{C}-O^-$$

Z Witter ion

$$\overset{+}{H_3N}-\underset{\underset{R}{|}}{\overset{\overset{H}{|}}{C}}-\overset{\overset{O}{||}}{C}-OH \xleftarrow{H^+} \overset{+}{H_3N}-\underset{\underset{R}{|}}{\overset{\overset{H}{|}}{C}}-\overset{\overset{O}{||}}{C}-O^- \xrightarrow[-H_2O]{HO^-} H_2N-\underset{\underset{R}{|}}{\overset{\overset{H}{|}}{C}}-\overset{\overset{O}{||}}{C}-O^-$$

Low pH (Acid Soln.)
Cation form (II)

Z Witter ion
Neutral form (I)

High pH (Basic soln.)
Anionic form (III)

Isoelectric point of α–amino acids

When an ionized amino acid is subjected to an electric field, it will exhibit migration towards the electrode of opposite charge. Depending on the pH of the surrounding medium, three scenarios can occur.

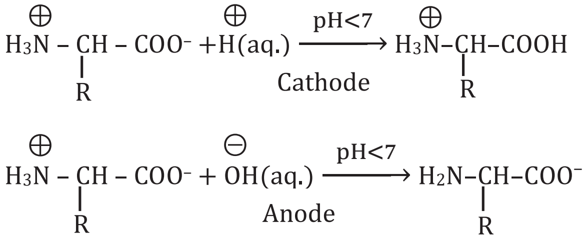
The positively charged form (II) will move towards the cathode, the neutral form (Zwitterion) will remain stationary, and the negatively charged form (III) will migrate towards the anode. The pH at which an amino acid displays no inclination to migrate in an electric field is referred to as its isoelectric point, which is a characteristic property of each amino acid.

For example, glycine has an isoelectric point at pH6.1.

Isoelectric Point

The isoelectric point is the pH at which an amino acid does not exhibit any directional migration when subjected to an electric field.

Due to its amphoteric nature, in an acidic solution, the amino acid exists as a positively charged ion and thus migrates toward the cathode. Conversely, in a basic solution, it exists as a negatively charged ion and migrates toward the anode.



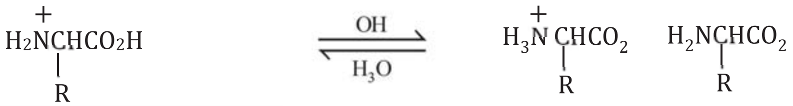
$$\overset{\oplus}{H_3N}-\underset{R}{\underset{|}{CH}}-COO^- + \overset{\oplus}{H}(aq.) \xrightarrow[\text{Cathode}]{pH<7} \overset{\oplus}{H_3N}-\underset{R}{\underset{|}{CH}}-COOH$$

$$\overset{\oplus}{H_3N}-\underset{R}{\underset{|}{CH}}-COO^- + \overset{\ominus}{OH}(aq.) \xrightarrow[\text{Anode}]{pH<7} H_2N-\underset{R}{\underset{|}{CH}}-COO^-$$

At a certain pH value, amino acids take on a neutral dipolar form, where the concentrations of both cations and anions are balanced, causing them not to migrate toward either electrode. This specific pH is known as the isoelectric point of the amino acid, and it varies among different amino acids.

Amino Acid as Dipolar Ions

Amino acids possess both a basic group ($-NH_2$) and an acidic group ($-COOH$). In their solid, dry state, amino acids assume the form of dipolar ions, where the carboxyl group appears as a carboxylate ion, $-CO_2^-$, and the amino group exists as an ammonium ion, $-NH_3^+$ (These dipolar ions are also known as zwitterions.) When in an aqueous solution, an equilibrium is established between the dipolar ion and the anionic and cationic forms of an amino acid.



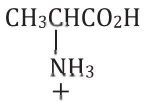
$$\overset{+}{H_2N}\underset{R}{\underset{|}{CH}}CO_2H \quad \underset{H_3O}{\overset{OH}{\rightleftharpoons}} \quad \overset{+}{H_3N}\,\underset{R}{\underset{|}{CH}}CO_2 \quad H_2N\underset{R}{\underset{|}{CH}}CO_2$$

Cationic form (Predominant in strongly acidic solutions, eg., At pH 0)

Dipolar ion

Anionic form (Predominant in strongly basic solutions, e.g., At pH 14

When alanine is dissolved in a highly acidic solution (e.g., pH 0), it predominantly exists in a positively charged cationic form. In this state, the amine group is protonated, carrying a formal +1 charge, while the carboxylic acid group remains neutral without a formal charge. As observed in most α-amino acids, the pK_a for the carboxylic acid hydrogen of alanine is significantly lower (2.3) compared to the pK_a of a typical carboxylic acid (e.g., propanoic acid, pK_a 4.89):



$$CH_3\underset{\underset{+}{NH_3}}{\underset{|}{C}}HCO_2H$$

Cationic form of alanine

$pK_a = 2.3$

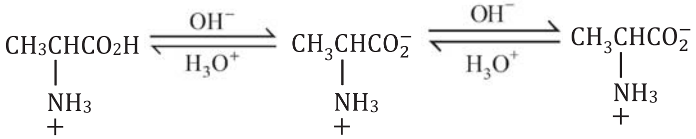
CH_3CHCO_2H

Propanoic acid

$pK = 4.89$

The inductive effect of the adjacent ammonium cation, which aids in stabilizing the carboxylate anion that forms when the carboxyl group loses a proton. Proton loss from the carboxyl group in a cationic α-amino acid results in an electrically neutral molecule (in the form of a dipolar ion). This equilibrium is depicted in the red-shaded section of the equation below.

The protonated amine group of an α-amino acid is also acidic, albeit to a lesser degree than the carboxylic acid group. The pKa of the ammonium group in alanine is 9.7. The equilibrium for proton loss from the ammonium group is illustrated in the blue-shaded part of the equation below. It's important to note that in α-amino acids, the carboxylic acid proton is always lost before a proton from the ammonium group.



$$CH_3\underset{\underset{+}{NH_3}}{\underset{|}{C}}HCO_2H \underset{H_3O^+}{\overset{OH^-}{\rightleftharpoons}} CH_3\underset{\underset{+}{NH_3}}{\underset{|}{C}}HCO_2^- \underset{H_3O^+}{\overset{OH^-}{\rightleftharpoons}} CH_3\underset{\underset{+}{NH_3}}{\underset{|}{C}}HCO_2^-$$

Cationic form Dipolar ion Anionic form

$pK_a = 2.3$ $pK_a = 9.7$

The ionization state of an α-amino acid at a specific pH is determined by a combination of two equilibria, as illustrated in the equation provided for alanine. The isoelectric point (pI) of an amino acid, such as alanine, can be calculated as the average of its two pKa values, denoted as pKa_1 and pKa_2. For alanine, these pKa values are 2.3 and 9.7, respectively. To determine the pI, we calculate the average as follows:

$$pI = ½ (pKa_1 + pKa_2)$$
$$pI = ½ (2.3 + 9.7)$$
$$pI = ½ (12.0)$$
$$pI = 6.0$$

Therefore, the isoelectric point of alanine is pH 6.0. At this pH, alanine exists in a neutral, dipolar ion state with an equal concentration of cationic and anionic forms.

When a base is introduced to a solution of alanine's predominantly cationic form (which starts at a very low pH, like 0), the initial proton to be eliminated is the one associated with the carboxylic acid, as mentioned earlier. For alanine, reaching a pH of 2.3 results in the removal of the acid proton from half of the alanine molecules. This specific pH corresponds to the pKa of the alanine carboxylic acid proton, and this relationship can be demonstrated using the Henderson-Hasselbalch equation. The Henderson-Hasselbalch equation is used to describe the relationship between an acid (HA) and its conjugate base (A^-), and it can be expressed as follows:

$$pK_a = pH + \log \frac{[HA]}{[A^-]}$$

When the acid has undergone neutralization for half of its molecules,

b) Copolymers represent another category of polymers that consist of more than one type of subunit or monomer.

For instance,

In the previously mentioned example, styrene and maleic anhydride monomers alternate with each other. Copolymers can also exist in a block copolymer form.

Ex.: Co-polymers can be random as well.

— B – A – A – B – A – B – B – A – B – A –B – B – A —

A and B are monomers.

- There are many polymers in nature.

Ex: Cellulose, starch, pepsin, insulin, egg albumin, rubber, DNA (Deoxyribonucleic acid) etc. These are called Biopolymers. Man-made polymers are, Nylon, Terylene, Polythene, Polystyrene, PVC (Polyvinyl chloride), Bakelite, Perspex, Polydioxanone etc.

- ➢ The properties of a polymer solution are strikingly different from those of a true solution.

For example, when polyvinyl alcohol is added to water, it swells.

a) Its shape gets distorted and after a long time it dissolves.

b) When more of polymer is added to a given solvent, saturation point is not reached. The mixture of polymer and solvent assumes a soft dough-like consistency.

  - ➢ Addition polymers and condensation polymers are two important types of polymers.
  - ➢ Polymer can be described as linear, branched and network.

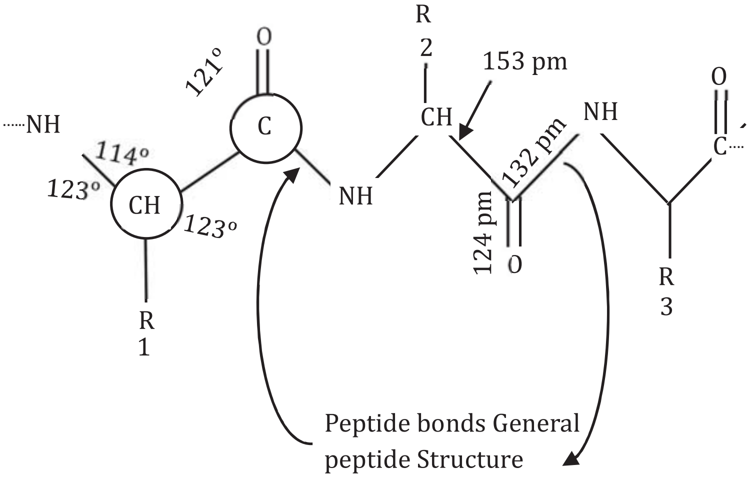
Peptide & Proteins

Peptides and proteins are fundamental molecules in biology, playing crucial roles in various biological processes.

Proteins

In the previous section, you explored the polymers derived from monosaccharides, which function as structural elements in plants and act as energy reserves in animals. In this section, we will delve into another category of natural polymers known as peptides and proteins.

Peptides represent biologically significant polymers, where 2-amino acids are linked through amide connections. These amide linkages are created through the interaction of the carboxylic group of one amino acid with the amino group of another. These bonds are also referred to as peptide bonds. The general structure of a peptide is depicted below:



Peptides can be categorized as dipeptides, tripeptides, or tetrapeptides, depending on whether they consist of two, three, or four amino acids, respectively. Peptides comprising up to 50 amino acids are referred to as polypeptides. An example of a significant naturally occurring nonapeptide is bradykinin, which is found in blood plasma and plays a role in blood pressure regulation.

Arg—Pro — Pro — Gly — Phe — Ser — Pro — Phe — Arg

Bradykinin

Configuration of Proteins

(a) Biological nature or function of protein was confirmed by its conformation.

(b) This conformation is of 4 types

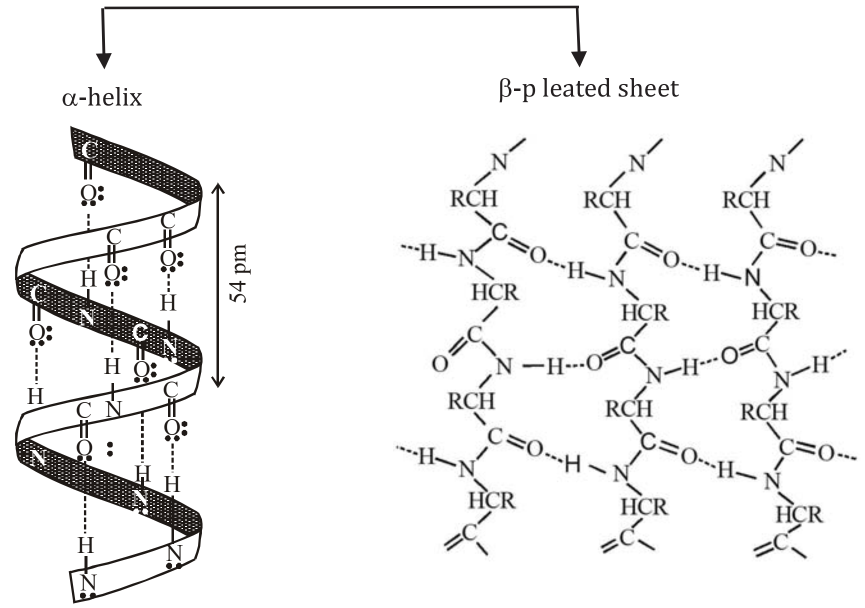
Primary
Secondary
Tertiary
Quatemany

Primary Structure

- This structural concept was introduced by Frederick Sanger in 1953 while studying insulin (for one of its chains).
- The primary structure is verified by a single polypeptide chain arranged linearly.
- All amino acids are linked together in a straight chain through peptide bonds.
- This structure lacks biological significance and is swiftly transformed into other forms.

Secondary Structure

- In this structure, the straight chain gradually transforms from its irregular shape into coils.
- The secondary structure is characterized by the presence of hydrogen bonds and peptide bonds.
- These hydrogen bonds form between the hydrogen of the amino group and the oxygen atom of the carboxylic acid group.
- This structure can be categorized into two types.



(i) α-helix

- Chain is spiral
- 3.7 atoms in one coiling
- Right-handed circular.

Ex. Myosin, Keratin etc.

(ii) β-pleated sheet

- Structure of protein is not arranged in a sequence.

- Polypeptide chain is parallel to each other
- H - bond form by near chains

Ex. Silk fibres.

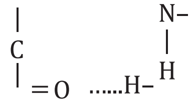
Tertiary Structure

- In this structure of protein atoms are highly coiled and form a spherical form.

Ex. Albumin

- This structure is formed by 4 regular hydrogen bonds which makes a regularity in it.

(i) Hydrogen bond



$$\overset{|}{\underset{|}{C}}{=}O\ ......H-\overset{\overset{N-}{|}}{H}$$

Hydrogen bond

- They are formed between oxygen of acidic amino acid and H of basic amino acid.

(ii) Hydrophobic bond

- Non - polar side chains of neutral amino acid tend to be closely associated with one another in proteins.
- Present in between the amino Acid.
- These are not true bonds.

(iii) logic bond

$$-COO^{-}......H_3{}^{+}N-$$

Ionic bond

- These are salt bonds formed between oppositely charged groups in side chains of Amino acids

Eg. Aspartic acid, Glutamic acid

(iv) Disulphide bonds

| ——— S - S —— |

- Relatively stable bond and thus is not broken readily under usual conditions of denaturation.
- Formed between the -SH group of Amino acid

Ex. Cystine and Methionine.

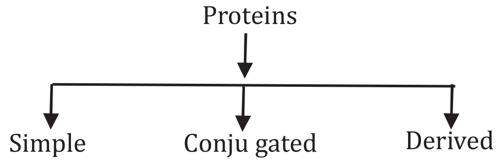
Quaternary Structure

- When 2 or more polypeptide chains united by forces other than covalent bonds (i.e., not
- peptide and disulphide bonds) are called Quaternary structure.
- It is most stable structure.

Ex. Hemoglobin

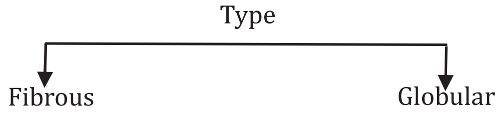
Types of Proteins

Classification of protein is based upon three general properties shape, Solubility and Chemical composition.



(1) Simple Proteins

- ➢ It is formed of only Amino Acids



(i) Fibrous

- ➢ It is insoluble
- ➢ It is of elongated shape.
- ➢ It is highly resistant to digestion by proteolytic enzymes.
- ➢ Their main function - Protection.

Ex. Collagen, Keratin etc

(ii) Globular

- ➢ These are spherical and oval in shape. Chains are highly coiled
- ➢ These are soluble.

Ex. Albumin

(2) Conjugated Proteins

- ➢ These are complex proteins in which protein molecule is combined with characteristic non-amino acid substance.
- ➢ Non-amino acid or non-protein part is called as prosthetic group

Ex. Nucleoproteins

(Protein + Nucleic acid),

Phosphoproteins (Protein + $(PO_3)^{2-}$)

Ex. Casein of milk., Vitelline of egg - yolk

(3) Derived Proteins

These are obtained as a result of partial hydrolysis of natural proteins.

Eg. Proteose, Metaproteins, Peptones

Denaturation of Proteins

When a protein, in its natural state, undergoes a physical alteration such as a temperature shift or a chemical transformation like pH change, it disrupts the native structure of the protein, resulting in what is referred to as denatured proteins.

Denaturation can take either a reversible or an irreversible form.

For instance, the irreversible denaturation of proteins can be observed in the coagulation of eggs when boiled.

Nevertheless, it is now known that in certain instances, this process is indeed reversible. This reversal of denaturation is termed renaturation.

Test of Protein

(a) Upon heating with concentrated HNO_3, a yellow precipitate is formed. Upon further heating and the addition of NH_4OH, the solution turns red, indicating a positive Xanthoproteic test.

(b) When proteins are mixed with (NH_4OH) and dilute $CuSO_4$, they produce a blue-violet color, which is a positive result in the biuret test.

(c) Million's reagent, consisting of a solution of mercuric and mercurous nitrates in nitric acid with a small amount of nitrous acid, is used to react with proteins. When the solution is heated, it results in either a red precipitate or a color change.

(d) The Ninhydrin reaction is characterized by proteins, peptides, and α-amino acids producing a distinct blue color when treated with ninhydrin.

Biological Importance of Protein

(a) Constituent of the plasma membrane.
(b) Every enzyme is a protein.
(c) Several hormones are proteins.
(d) Antigens and antibodies are proteins.
(e) Actin and myosin are essential proteins in muscle contraction.
(f) Proteins play a crucial role in growth, regeneration, and repair processes.
(g) Caloric value of 4.0 kcal.

Peptides

Peptides consist of brief sequences of amino acids that are interconnected via peptide bonds. Amino acids, organic compounds comprising an amino group (-NH2) and a carboxyl group (-COOH), serve as the building blocks of these molecules. Peptides are generally smaller in size compared to proteins, varying from a mere handful of amino acids to approximately 50 in length.

These molecular entities play pivotal roles in a multitude of biological processes. They partake in functions crucial for organismal survival and well-being, including but not limited to signaling between cells, catalyzing enzymatic reactions, and providing structural reinforcement to biological structures.

An array of peptides exists in biological systems, each tailored for specific functions. Notable examples encompass hormones like insulin and glucagon, which regulate blood sugar levels, neurotransmitters such as endorphins involved in pain regulation and mood modulation, and signaling molecules like cytokines, which coordinate immune responses and cellular communication.