## Protein

Proteins are one of the macronutrients. Proteins form the main part all cells and tissues, making them essential for growth and repair.

Elemental compositions of proteins

Proteins are made up of four elements: carbon (C), hydrogen (H), oxygen (O) and nitrogen (N).

Proteins are the only nutrients that contain nitrogen, which is essential for growth.

Some proteins contain small quantities of sulfur (S), iron (Fe) and phosphorus (P).

Chemical structure of proteins

Proteins are large molecules composed of amino acids. Amino acids are joined together by peptide links to form polypeptide chains that make up proteins.

Basic structure of an amino acid

Each amino acid contains:

An amino group (NH2) (basic)

A carboxyl group (COOH) (acidic)

A central carbon (C)

A single hydrogen (H)

A variable group (R): changes with each amino acid.

Basic structure of an amino acid:

H

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NH2— C —COOH

|

R

Examples of amino acids

The variable group (R) is different in each amino acid.

| | |
|---|---|
| When the variable group (R) is hydrogen (H) the amino acid is glycine.<br>H<br>\| | When the variable group (R) is HS-CH2 the amino acid is cysteine.<br>H<br>\| |

| | |
|---|---|
| NH2 — C — COOH<br>           \|<br>           H | NH2 — C — COOH<br>           \|<br>      HS — CH2 |

Essential and non-essential amino acids

The human body uses 20 different amino acids to make all the proteins it needs to function. These are all found in food. They are divided into two groups: essential and non-essential amino acids.

| Essential amino acids | Non-essential amino acids |
|---|---|
| Can't be manufactured by the body, therefore must be obtained from food. There are ten essential amino acids. Adults require eight of these and children require ten. | Can be manufactured by the body, therefore do not need to be obtained from food. There are ten non-essential amino acids. |
| Valine<br>Lysine<br>Leucine<br>Isoleucine<br>Phenylalanine<br>Methionine<br>Threonine<br>Tryptophan<br>Histidine (children)<br>Arginine (children) | Alanine<br>Aspartic acid<br>Cysteine<br>Ornithine<br>Serine<br>Asparagine<br>Proline<br>Tyrosine<br>Glycine<br>Glutamic acid |

Peptide links

Peptide links are formed when two amino acids join together. This results in the loss of a water ($H_2O$) molecule and is called a condensation reaction.

Stages in the formation of peptide links

1. The COOH (acidic) group of one amino acid reacts with the NH2 (basic) group of another.

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       H   O        H   H
       |   ||       |   |
NH2 —  C — C — OH   N — C — COOH
       |            |   |
       R            H   R
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2. The COOH (acidic) group loses an OH group. The NH2 (basic) group loses a hydrogen (H) atom. The hydrogen (H) atom and the OH group join together to form a water (H2O) molecule that is lost.

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          H    O         H    H
          |    ||        |    |
NH2 — C — C — OH    N — C — COOH
          |              |    |
          R              H    R
```

3. The result is a CO-NH bond. This new molecule is called a dipeptide (two amino acids joined together). When more than 20 amino acids join together, a polypeptide is formed. When more than 50 amino acids join together, a protein is formed. Each protein consists of one or more polypeptide chains.

```
          H    O         H
          |    ||        |
NH2 — C — C — N — C — COOH
          |         |    |
          R         H    R
               |
              H2O
```

The reverse of the condensation reaction is called hydrolysis. Hydrolysis involves the addition of water and enzyme action. It occurs during digestion, when proteins are broken down into individual amino acids.

Structure of amino acids

| Primary structure |
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| Primary structure is the order or sequence of amino acids in protein chains.<br>Amino acids can be arranged in many different combinations. Insulin, one of the simplest proteins, contains 51 amino acids. |

| Secondary structure |
| --- |
| Secondary structure involves the folding of the primary structure of proteins into definite shapes. |

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| Polypeptide chains either fold in on themselves or cross-link with another polypeptide chain.<br>This causes the chains to form a spiral shape. Cross-links give proteins their unique properties, e.g., gluten its elasticity.<br>There are two main types of cross-links: disulfide bonds and hydrogen bonds. |
| Disulfide bonds |
| Disulfide bonds occur when two sulfurs from two amino acids join together from either a single polypeptide chain or two different polypeptide chains.<br>The amino acid cysteine contains sulfur. Two cysteine amino acids can form a disulfide bond.<br>Insulin contains disulfide bonds. |
| Hydrogen bonds |
| Hydrogen bonds occur when a hydrogen (H) from the N-H group of one amino acid join together from either a single polypeptide chain or two different polypeptide chains.<br>The amino acids serine and tyrosine are capable of forming hydrogen bonds.<br>Collagen contains hydrogen bonds. |

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| Tertiary structure |
| Involves the folding of the secondary structure of proteins into three-dimensional shapes.<br>Further cross-linking between amino acids forms definite shapes, which may be fibrous (elongated) or globular (folded over itself to form a compressed unit). |
| Fibrous |
| Shape<br>Polypeptide chains are arranged in straight, spiral or zigzag shapes. |
| Properties<br>Insoluble in water.<br>Not easily denatured. |
| Examples<br>Gluten (wheat)<br>Elastin and collagen (meat connective tissue) |
| Globular |
| Shape<br>Polypeptide chains are arranged in a globular (spherical) shape. |
| Properties<br>Soluble in water.<br>Easily denatured. |
| Examples<br>Ovalbumin (egg white)<br>Lactalbumin (milk) |

Classification of proteins

Proteins can be classified as simple proteins or conjugated proteins.

Simple proteins

| Group | Sub-group | Examples | Sources |
| --- | --- | --- | --- |
| Animal | Fibrous | Elastin<br>Collagen | Meat connective tissue<br>Meat connective tissue |
| | Globular | Ovalbumin<br>Lactalbumin | Egg white<br>Milk |
| Plant | Glutenins | Glutenin<br>Oryzenin | Wheat<br>Rice |
| | Prolamines | Gliadin<br>Zein | Wheat<br>Maize |

Conjugated proteins

Conjugated proteins form when proteins combine with a non-protein molecule.

| Group | Examples | Sources |
| --- | --- | --- |
| Lipoproteins (lipid and protein) | Lecithin | Eggs |
| Phosphoproteins (phosphate and protein) | Caseinogen | Milk |

Sources of protein

Animal sources

Meat, fish, eggs, milk and cheese.

Plant sources

Beans, nuts, lentils, peas and cereals.

Biological value of proteins

Biological value protein is a measure of the protein quality in a food and it is displayed as a percentage (%). It is determined by the number of essential amino acids a food contains in proportion to the needs of the body. For example, a 100% biological value protein food contains all the essential amino acids in proportion to the needs of the body.

High biological value (HBV) proteins (complete proteins): contain all essential amino acids. These proteins are mostly found in animal sources, with the exception of soya beans.

| Food | Biological value | Proteins present |
| --- | --- | --- |
| Eggs | 100% | Ovalbumin, vitellin and livetin |

| | | |
|---|---|---|
| Milk | 95% | Caseinogen, lactalbumin and lactoglobulin |
| Meat | 80-90% | Collagen, actin, elastin, myosin and globulin |
| Fish | 80-90% | Collagen, actin and myosin |
| Cheese | 84% | Casein |
| Soya beans | 74% | Glycinin |

Low biological value (LBV) proteins (incomplete proteins): lack one or more of the essential amino acids. These proteins are mostly found in plant sources, with the exception of gelatine.

| Food | Biological value | Proteins present |
|---|---|---|
| Rice | 67% | Oryzenin |
| Wheat | 53% | Gluten |
| Maize | 40% | Zein |
| Meat bones | 0% | Gelatine |

Complete role/supplementary value of protein

Low biological value (LBV) proteins are deficient in one or more essential amino acids. Consuming two LBV protein foods together (each lacking essential amino acids) can ensure all essential amino acids are obtained. This is particularly important for vegans and vegetarians. E.g., beans and toast, hummus and pitta bread and lentil dahl and Naan.

Properties of proteins

Denaturation

Denaturation is a change in the nature of a protein chain. It involves the unfolding of a protein chain, resulting in an irreversible change in shape. It is brought about by physical or chemical means including heat, chemicals, mechanical action and enzymes. This results in the hardening or setting of protein food, known as coagulation.

Causes of denaturation

Heat

Heat causes protein chains to unfold and bond together, causing food to coagulate and set.

Culinary application: egg whites coagulate and change from translucent to opaque at 60°C and egg yolks coagulate at 68°C. Dry heat, e.g., grilling, causes meat fibres to shrink, toughen and lose water, producing a dry texture. Moist heat, e.g., boiling, tenderises meat by converting collagen to gelatine.

Chemicals

Lowering or raising pH levels by the addition of acids and alkalis can denature the structure of proteins.

Culinary application: a vinegar-based marinade tenderises meat by denaturing proteins.

Mechanical action

Mechanical action, e.g., whipping or beating, causes protein chains to unfold and partial coagulation to occur.

Culinary application: meringues and sponges.

Enzymes

Enzymes cause a change to the nature of proteins' structure.

Culinary application: the enzyme rennin in rennet causes caseinogen in milk to coagulate during cheese-making, forming curds and whey. Proteolytic enzymes, e.g., papain (from papaya), tenderise meat.

Elasticity

Some fibrous proteins, e.g., gluten in wheat, are quite elastic.

Culinary application: gluten makes dough elastic enough to trap the $CO2$ gas produced by yeast, helping it to rise.

Maillard reaction

The Maillard reaction is the non-enzymic browning of food due to a reaction between certain amino acids and sugars under dry heat. It produces an attractive brown colour and a crust with an appetising flavour.

Culinary application: shortbread biscuits, roast potatoes and roast meat.

Solubility

Most proteins are insoluble in water, apart from collagen in meat (soluble in hot water) and egg albumin (soluble in cold water).

Culinary application: moist heat tenderises meat by converting collagen to gelatine.

Gel formation

When collagen (present in the bones and skin of meat) is heated it is converted to gelatine. Gelatine can absorb large amounts of water when heated, as protein chains uncoil and water becomes trapped. This forms a sol. On cooling, a sol forms a gel, a semi-solid viscous solution that has a three-dimensional protein matrix in which water molecules become trapped.

Culinary application: cheesecakes and jelly sweets.

Foam formation

When an egg white is whisked, protein chains unfold and air bubbles form. The protein chains entrap air, creating a foam. Whisking also creates heat that begins to set the egg albumin. This is known as a temporary foam. It will collapse after a while unless heated to coagulate and set as a permanent foam.

Culinary application: meringues.

Effects of dry and moist heat on proteins

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|---|---|
| Dry and moist heat | Coagulation, e.g., egg whites coagulate at 60°C and egg yolks at 68°C.<br>Colour change, e.g., myoglobin (red pigment) in meat changes to haematin (brown pigment).<br>Overcooking causes proteins to become indigestible. |
| Dry heat | Maillard reaction, e.g., roast beef |
| Moist heat | Tenderising meat: collagen in meat converts to gelatine, causing the fibres to tenderise, e.g., pulled pork. |

Biological functions of proteins

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|---|---|
| Structural proteins<br>(used to build parts of the body) | Production of cell membranes, muscle tissue and skin.<br>Cell repair and replacement.<br>Growth. |
| Physiologically active proteins<br>(assist with the normal functioning of the body) | Production of:<br>Hormonal proteins: help to coordinate bodily activities, e.g., production of insulin.<br>Enzymes: speed up chemical reactions, e.g., pepsin speeds up the breakdown of proteins in food.<br>Antibodies (immunoglobulins): defend the body from harmful substances, e.g., viruses.<br>Blood proteins: move molecules around the body, e.g., haemoglobin transports oxygen through the blood.<br>Nucleoproteins (DNA): make up the hereditary material in chromosomes. |
| Nutrient proteins<br>(play a nutritional role within the body) | Provide the body with essential amino acids. |

| | |
|---|---|
| | Excess can be used as a source of energy when carbohydrate and fat reserves are used. |

Recommended Daily Allowance (RDA)/Reference Intake (RI)

The protein requirements of an individual depend on body weight and rate of growth. On average, adults need approximately 0.75 g of proteins per kg of body weight per day. During periods of rapid growth, e.g., childhood, adolescence and pregnancy, more proteins are required.

| Group | RDA/RI (g) |
|---|---|
| Children | 30-50 g |
| Adolescents | 60-80 g |
| Adults and older people | 50-75 g |
| Pregnant and lactating women | 70-85 g |

Energy value of proteins

1 g of proteins provides 4 kcal of energy (17 KJ).

Digestion of proteins

During digestion, water and enzymes break protein chains into separate amino acids. This process is called hydrolysis.

Mouth: food is chewed into small pieces by the teeth.

Stomach: secretes gastric juice containing:

Hydrochloric acid (HCL), which denatures proteins.

The enzyme rennin, which breaks down caseinogen into casein.

The enzyme pepsin, which breaks down proteins into peptones.

Pancreas: secretes pancreatic juice into the duodenum (the first part of the small intestine). The juice contains the enzyme trypsin that breaks down peptones into peptides.

Small intestine: the ileum (final section of the small intestine) secretes intestinal juice containing the enzyme peptidase that breaks down peptides into amino acids.

The amino acids are now ready to be absorbed and utilised by the body.

| Organ or gland | Secretion | Enzymes | Substrate | Product |
|---|---|---|---|---|
| Stomach | Gastric juice | Rennin<br>Pepsin | Caseinogen<br>Proteins | Casein<br>Peptones |

| | | | | |
|---|---|---|---|---|
| Pancreas | Pancreatic juice | Trypsin | Peptones | Peptides |
| Small intestine (ileum) | Intestinal juice | Peptidase | Peptides | Amino acids |

Absorption and utilisation of proteins

After digestion the amino acids are ready to be absorbed by the small intestine. To enter, they pass through the wall of the villi and into the bloodstream.

Next, the hepatic portal vein transports the amino acids to the liver.

In the liver, amino acids are:

Used to maintain and repair liver cells.

Passed into the bloodstream and body tissues to form new cells, hormones, enzymes and antibodies.

Excess amino acids are deaminated to produce heat and energy.

Deamination

Deamination is the process through which excess amino acids are broken down by the body in the liver.

The NH2 group of the amino acid is removed, converted to ammonia, then to urea and excreted through the kidneys.

The COOH group of the amino acid is oxidised to produce energy and heat.

Excess protein

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|— Liver — |

NH2 COOH

| |

Converted Oxidised for heat and energy

to ammonia and urea

|

Excreted as urine through the kidneys