Chapter III: Bacterial Nutrition

Introduction

The study of bacterial nutrition examines the elemental, energy, and specific requirements needed for bacterial growth and metabolism, as well as the physicochemical factors that influence them.

To survive and multiply, bacteria require mineral and organic substances called nutrients. The degradation of these nutrients, provided in culture media, supplies them with simple elements (carbon, nitrogen, minerals) and energy, which they reuse to synthesize their own structural and enzymatic components.

All bacteria share some common requirements, such as water, an energy source, a carbon source, a nitrogen source, and mineral elements. By examining the chemical composition of a bacterial cell, we can infer its nutritional needs. The bacterial cell is primarily composed of water, accounting for 75 to 80% of its total weight.

The dry matter consists of proteins (55%), rRNA (16.7%), tRNA (3%), mRNA (0.8%), DNA (3.1%), lipids (9.1%), lipopolysaccharides (3.4%), peptidoglycans (2.5%), vitamins (2.9%), and inorganic ions (1.0%).

I. Elementary needs

The dry matter of a bacterium consists of several macro-elements: C, O, H, N, S, and P, which are components of organic molecules; K, Ca, Na and Mg, which exist as cations in the cell and play various roles. Some elements are only present in "trace" amounts, such as Mn, Zn, Co, Ni, Cu, Fe and Mo. These are trace elements (or micro-elements) that are essential for microbial metabolism, as they act as cofactors or activators of enzymatic reactions. The elemental requirements vary from one species to another, depending on their environment.

I.1. Energy

Bacteria utilize two primary sources of energy:

- **Light energy** (in **phototrophic** bacteria), converted into ATP using pigments such as chlorophylls, bacteriochlorophylls, and carotenoids:
  - If the electron donor is inorganic, the bacterium is **photolithotrophic** and can grow in a purely mineral medium, similar to plants.
  - If the electron donor is organic, the bacterium is **photoorganotrophic**.
- **Chemical energy** (in **chemotrophic** bacteria), obtained from the oxidation of:
  - Inorganic molecules (**chemolithotrophs**)
  - Organic molecules (**chemoorganotrophs**)

I.2. Carbon

Carbon is one of the most abundant elements in bacteria and must be supplied in sufficient quantities. Based on carbon source, microorganisms fall into two major categories:

- **Autotrophic bacteria**: These can grow in an inorganic medium using carbon dioxide (CO_2) or bicarbonate ions (HCO_3^-) as their sole carbon source to synthesize organic constituents.
- **Heterotrophic bacteria**: These require organic carbon sources such as sugars, organic acids, peptides, or amino acids. Some heterotrophs assimilate a wide range of organic compounds, while others have limited metabolic capacity and utilize only specific substrates.

I.3. Nitrogen

Nitrogen is essential for protein synthesis. Bacteria can utilize nitrogen in various forms:

- **Inorganic nitrogen**:
  - Molecular nitrogen (N_2) from the atmosphere (nitrogen-fixing bacteria)
  - Nitrites (NO_2^-)
  - Nitrates (NO_3^-) : utilized by bacteria possessing assimilatory nitrate reductase
  - Ammonia (NH_3) or ammonium salts: the most readily assimilable form
- **Organic nitrogen**: Found in amine groups ($R–NH_2$) of amino acids and other organic compounds.

I.4. Phosphorus

Phosphorus is a key constituent of nucleic acids (DNA, RNA), ATP, and many coenzymes. It is assimilated mainly as inorganic phosphate (derived from H_3PO_4) and plays a crucial role in energy storage and transfer.

I.5. Sulphur

Sulfur is a component of some amino acids (methionine, cysteine) and therefore of proteins, appearing in thiol (-SH) groups. It is incorporated primarily as sulfate (SO_4^{2-}) or through organic sulfur compounds.

1.6. Other mineral elements

In addition to the macro-elements listed above (C, H, O, N, S, P, Na, Mg, K), microorganisms require trace elements (**micro-elements**) in very small amounts. These include iron (Fe), copper (Cu), cobalt (Co), zinc (Zn), manganese (Mn), and molybdenum (Mo), which often serve as enzymatic cofactors.

II. Growth factors (specific requirements)

In addition to basic nutrients, some bacteria require specific organic compounds called growth factors for growth. These bacteria are unable to synthesize these substances and must therefore obtain them from their environment or culture media.

Bacteria can be classified into two types based on their growth requirements:

- **Prototrophic bacteria**: Can grow with only basic nutrients (water, an energy source, carbon, nitrogen and minerals).
- **Auxotrophic bacteria**: Require one or more growth factors in addition to basic nutrients.

II.1. Nature of growth factors

Growth factors fall into three main groups:

- Amino acids: Required for protein synthesis.
- Purines and pyrimidines: Required for nucleic acid synthesis.
- Vitamins: Act as coenzymes or coenzyme precursors. For example, nicotinic acid (vitamin B_3) is a precursor of nicotinamide

II.2. Properties of growth factors

- Active at very low concentrations: Growth factors are effective at minimal concentrations
- High specificity: Even minor structural modifications can render a growth factor biologically inactive.

Satellitism

The growth factor requirement of one bacterial species can sometimes be fulfilled by another species that synthesizes and releases the needed compound. This phenomenon is known as satellitism.

III. Nutritional types of bacteria

Bacterial trophic types are defined by combining the sources of energy, electron donors (reducing power), and carbon.

Energy Source	Electron donor	Carbon Source	Trophic type
Light (Photo-)	Organic compounds (-organo-)	Organic (-heterotroph)	Photoorganoheterotrophic
		Inorganic (-autotroph)	Photoorganoautotrophic
	Inorganic compounds (-litho-)	Organic (-heterotroph)	Photolithoheterotrophic
		Inorganic (-autotroph)	Photolithoautotrophic
Chemical (Chemo-)	Organic compounds (-organo-)	Organic (-heterotroph)	Chemoorganoheterotrophic
		Inorganic (-autotroph)	Chemoorganoautotrophic
	Inorganic compounds (-litho-)	Organic (-heterotroph)	Chemolithoheterotrophic
		Inorganic (-autotroph)	Chemolithoautotrophic

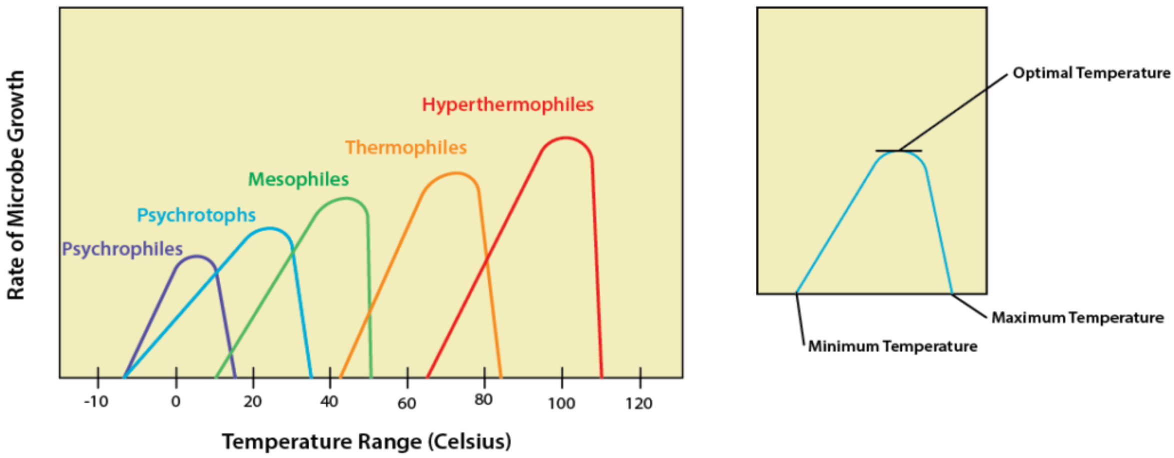
IV. Physicochemical parameters

Bacterial growth is strongly influenced by environmental physicochemical factors, which can either inhibit or promote nutrition. Each species has optimal ranges for these parameters.

IV.1. Temperature

Temperature affects the rate of biochemical reactions. Based on optimal growth temperature, bacteria are classified into:

- **Psychrophiles (cold-loving):** These bacteria grow best at low temperatures, with an optimum of ≤15°C and a maximum around 20°C.
- **Psychrotrophs (psychrotolerants):** Capable of growing at 0°C, but their optimal growth temperature ranges between 20°C and 25°C.
- **Mesophiles (moderate-temperature-loving):** Most bacteria, including the majority of human and animal pathogens, are mesophiles. Their optimal growth temperature ranges from 20°C to 40°C, with an optimum around 37°C (human body temperature).
- **Thermophiles (heat-loving):** These bacteria thrive at temperatures between 45°C and 80°C, with an optimum typically between 55°C and 65°C.
- **Hyperthermophilic bacteria:** Can grow at temperatures above 80°C.



IV.2. pH

Just like temperature, bacteria can grow within a specific pH range, which varies by species. Bacteria are classified into three categories based on their pH preference:

- **Acidophiles**: Optimal pH is acidic (below 5.5). Example: Lactic acid bacteria.
- **Neutrophiles**: Optimal pH is near neutrality. Most bacteria prefer to grow at pH values between 6.5 and 7.5.
- **Basophiles (alkaliphiles)**: Optimal pH >8.5. (e.g, some *Bacillus* and *Flavobacterium* species)

IV.3. Oxygen

Based on oxygen requirement and tolerance, bacteria are classified into:

- **Obligate aerobes**: Can only survive in the presence of atmospheric oxygen. They grow exclusively on the surface of cultures.
- **Obligate anaerobes**: Cannot tolerate oxygen, it is toxic to them. They grow only at the bottom of the tube.
- **Facultative anaerobes**: Can grow with or without oxygen by switching between respiration and fermentation
- **Microaerophiles**: Require reduced oxygen concentrations
- **Aerotolerant anaerobes bacteria**: Tolerate oxygen but do not use it; they rely exclusively on fermentation for energy.

IV.4. Osmotic pressure

Osmotic pressure reflects the total solute concentration in a medium. Most bacteria tolerate moderate variations due to their rigid cell wall, but some have specific adaptations:

- **Non-halophiles**: Optimal growth at low NaCl concentrations (0–1%) in standard media.
- **Halotolerant**: Can survive high salt concentrations but do not require them
- **Halophiles**: Require high NaCl concentrations for growth.
- **Osmophiles**: Tolerate or require high osmotic pressure due to sugars.

IV.5. Water Activity (Aw)

Water makes up 80–90% of bacterial cell weight and is essential for nutrient solubilization and enzymatic reactions. Water activity (*Aw*) measures the availability of free water. Examples of Aw requirements:

- *Acinetobacter spp.* (Aw > 0.99)
- *Clostridium botulinum* (Aw > 0.97)
- *Salmonella* and *Escherichia coli* start multiplying at Aw > 0.95
- *Staphylococcus aureus* can multiply at Aw = 0.85, but toxin production is only possible at Aw > 0.97
- *Listeria monocytogenes* can tolerate Aw = 0.83
- Halophilic bacteria can survive at Aw = 0.75
- Endospores can survive in environments devoid of free water.