Chapter III: Bacterial Nutrition

Introduction

The study of bacterial nutrition involves analysing the elementary, energetic, and specific requirements (growth factors) necessary for bacterial function and growth, as well as the physicochemical factors that may influence them.

To survive and multiply, bacteria require varying amounts of mineral and organic substances, known as nutrients or food substances. 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 microelements) 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

There are only two sources of energy available to living organisms:

- **Light energy** (in phototrophic bacteria), which is converted into ATP using pigments (chlorophylls, bacteriochlorophylls, carotenoids, etc.):
  - If the oxidizable substrate is mineral, the bacterium is called **photo-lithotrophic**: it can grow in a purely mineral environment, similar to plants.
  - If the oxidizable substrate is organic, the bacterium is called **photo-organotrophic**.
- **Chemical energy** (in chemotrophic bacteria), which comes from the oxidation of mineral molecules (**chemolithotrophs**) or organic molecules (**chemoorganotrophs**).

I.2. Carbon

Carbon is one of the most abundant elements in bacteria and must be supplied in sufficient quantities. The simplest carbon compound is carbon dioxide (CO_2) or bicarbonate ions (HCO_3^-).

Nutritional requirements for carbon classify microorganisms into two major categories:

- **Autotrophic bacteria**: These bacteria can grow in a mineral (inorganic) medium by using carbon dioxide (CO_2) or bicarbonate ions (HCO_3^-) as their sole carbon source to synthesize their carbon-based constituents.

- **Heterotrophic bacteria**: These bacteria require organic molecules (sugars and derivatives, organic acids, peptides, amino acids, etc.) for their growth. Some microorganisms can assimilate a wide range of organic substances, while others have a limited metabolic capacity, using only a few specific substrates or even just one.

I.3. Nitrogen

Nitrogenous compounds are essential for bacterial protein synthesis. Bacteria can utilize nitrogen in different forms:

- **Inorganic nitrogen**, in the form of:
  - ✓ The simplest form, molecular nitrogen (N_2) from the atmosphere.
  - ✓ Nitrites (NO_2^-).
  - ✓ Nitrates (NO_3^-): Utilized by bacteria possessing nitrate reductase B (assimilatory nitrate reductase).
  - ✓ Ammonia (NH_3): Used by bacteria which assimilate ammonium salts.
- **Organic nitrogen**, found in organic compounds ($R\text{-}NH_2$), where amine groups serve as a nitrogen source.

I.4. Sulphur

It is a component of certain amino acids (methionine, cysteine) and thus of proteins, in the form of thiol (-SH) groups. It is incorporated into the bacterial cell as sulphate or organic sulphur compounds.

I.5. Phosphorus

Phosphorus is a key component of nucleic acids (DNA, RNA), ATP, and many coenzymes. It is incorporated into bacteria in the form of inorganic phosphate (H_3PO_4 derivatives). It plays a crucial role in energy storage, accumulation, and distribution within the cell.

Requirements for other mineral elements

The previously mentioned elements are required in high concentrations in culture media and are called **macro-elements**: C, H, O, N, S, P, as well as Na, Mg, and K.

Microorganisms may also require other elements but in much smaller amounts. These are called **micro-elements** (trace elements): Cu, Co, Zn, Cl, Fe.

II. Growth factors (specific requirements)

In addition to basic elements, some bacteria require organic substances, known as **growth factors**, to develop. 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**: These bacteria can grow in the presence of water, an energy source, a carbon source, a nitrogen source, and mineral elements.
- **Auxotrophic bacteria**: In addition to the basic elements, these bacteria require one or more growth factors that they cannot synthesize themselves.

It is important not to confuse **growth factors** with **essential metabolites**. Both are strictly necessary organic compounds for bacterial nutrition. However, while a bacterium can synthesize an essential metabolite, a growth factor must be present in the environment because the bacterium cannot produce it. The concept of a growth factor is relative to a particular genus, species, or strain.

II.1. Nature of growth factors

Growth factors can be categorized into three main groups:

- **Certain amino acids**, which are necessary for protein synthesis.
- **Purine and pyrimidine bases**, which are essential for nucleic acid formation.
- **Vitamins**, which act as coenzymes or precursors of coenzymes. For example, vitamin B3 (nicotinic acid) is a precursor of nicotinamide, which is a key component of the NAD (nicotinamide adenine dinucleotide) coenzyme, one of the most important electron carriers.

II.2. Properties of growth factors

- **Active at very low concentrations**: Growth factors function effectively at minimal concentrations (e.g., in the range of µg/L for vitamins, 10 mg/L for bases, and 25 mg/L for amino acids).
- **Specific presence**: Even slight modifications in the structure of a growth factor can render it ineffective.

Satellitism

The growth factor needs of one bacterial species can sometimes be met by the presence of another species that synthesizes the required factor. In this relationship, a species uses the metabolic products of another species as a substrate for its own growth.

Example: *Haemophilus influenzae* grows only around a *Staphylococcus* streak on blood agar because *Staphylococcus* provides a necessary growth factor.

III. Nutritional types of bacteria

Bacterial trophic types are classified combining different sources of energy and carbon, as well as specifying the nature of electron donors used for chemical reactions.

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

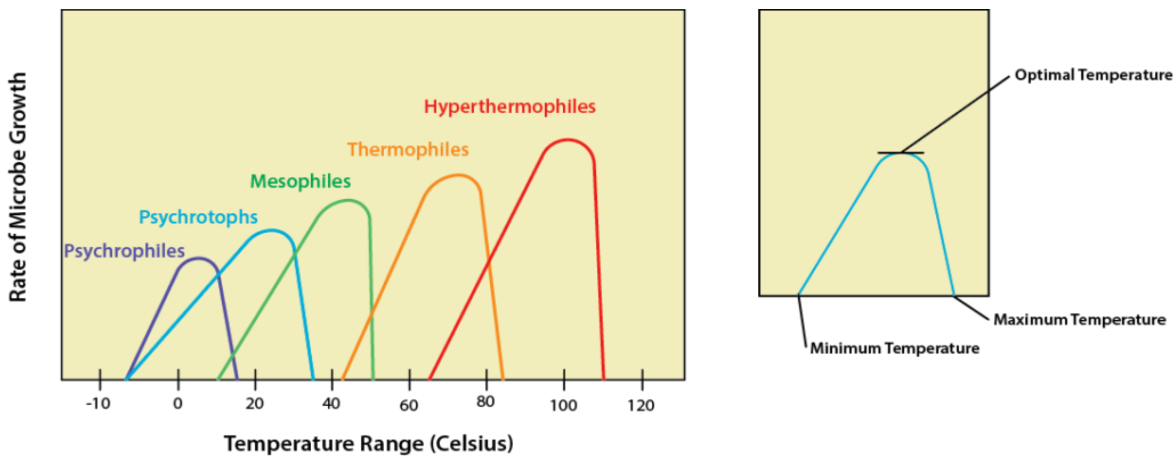
IV. Physicochemical parameters

Bacterial growth is largely influenced by the physicochemical parameters of the environment, which can either inhibit or promote bacterial nutrition. Each bacterium has optimal values for each factor, and based on these values, different bacterial categories are defined.

IV.1. Temperature

Temperature plays a crucial role in bacterial growth and metabolism by influencing the rate of biochemical reactions. Depending on the optimal temperature for growth, bacteria are classified into:

- **Psychrotrophic bacteria**: Can grow at 0°C, but their optimal growth temperature ranges between 20°C and 25°C.
- **Psychrophilic bacteria**: Cannot tolerate high temperatures (max 20°C) and prefer to grow below 15°C.
  Mesophilic bacteria: Optimal growth temperature is between 20°C and 40°C. Most microorganisms associated with humans and animals are mesophiles, growing between 25°C and 40°C, with an optimum at 37°C.
- **Thermophilic bacteria**: Optimal growth occurs between 45°C and 65°C, typically around 55°C.
- **Hyper-thermophilic bacteria**: Optimal growth temperature ranges between 70°C and 110°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 is basic (above 8). Examples: *Bacillus*, *Flavobacterium*.

IV.3. Oxygen

Depending on their respiratory type, bacteria are classified into:

- **Obligate aerobic bacteria**: Can only survive in the presence of atmospheric oxygen. They grow exclusively on the surface of cultures.
- **Obligate anaerobic bacteria**: Cannot tolerate oxygen, which is toxic to them. They grow only at the bottom of the tube.

- **Facultative anaerobic bacteria**: Can grow with or without oxygen. Their enzymatic system allows them to use oxygen when available and switch to fermentation when it is absent. Example: *Enterobacteria*.
- **Microaerophilic bacteria**: Require only a low oxygen concentration for growth. Example: *Campylobacter*.
- **Aerotolerant anaerobic bacteria**: Tolerate oxygen but do not use it; they rely exclusively on fermentation for energy. Example: *Lactobacilli*.

IV.4. Osmotic pressure

Osmotic pressure reflects the total concentration of ions and molecules in a solution. Most bacteria are not highly sensitive to osmotic pressure variations due to their rigid cell wall. However, rarely microorganisms can be evaluated as osmophilic and halophilic These bacterial groups are distinguished:

1. **Non-halophilic bacteria:** Grow in environments characterized by low solute concentration, with an optimal NaCl concentration of 0–1% in standard media.
2. **Halotolerant bacteria:** can survive in environments with high salt (NaCl) concentrations, but they do not require salt for growth. Examples: *Staphylococcus aureus*
3. **Halophilic bacteria:** They require high NaCl concentrations for growth.
4. **Osmophilic bacteria:** Tolerate or require sugar-rich environments (high osmotic pressure due to glucose, sucrose, etc.).

IV.5. Water Activity (Aw)

Water constitutes 80-90% of the bacterial cell weight and plays a fundamental role in solubilizing nutrients, transporting them, and enabling hydrolysis reactions. The **water activity (Aw)** quantifies the availability of free water in an environment.

Some bacteria require an Aw value above 0.97 for growth. Examples:

- *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.