BACTERIA

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Introduction

Bacteria are unicellular organisms, in other words they are made of a single cell. Bacteria were the first organisms that lived on the Earth. They appeared 3 billion years ago in the waters of the first oceans. Bacteria or prokaryotes are the most widespread living beings in the Earth: in a spoonful of soil, for example, it is possible to find up to 10,000 billion bacteria. Their size is extremely small, in fact most bacteria cells have a diameter that ranges from 1 to 10 microns (one micron is equivalent to one thousandth of a millimeter): a line of one thousand neatly arranged bacteria, would be only one millimeter long.

Bacteria knowledge

Bacteria or prokaryotes are the most common living beings on Earth: one spoonful of soil can contain, for instance, up to 10,000 billion bacteria. They are unicellular organisms, i.e. they consist of one cell only. They are very small in size, since a large part of bacterial cells have a diameter of 1 to 10 microns (one micron equals one thousandth of a millimeter), so an orderly row of one thousand bacteria would be just one millimeter long. Bacterial cells, unlike the cells of superior organisms (eukaryotes), do not have organelles enwrapped in membranes (nucleus, Golgi apparatus…) or chromosomes. Chromosomes are structures made of DNA wrapped around proteins, called histones, and their purpose is to make the long DNA molecules contained in the nucleus more compact and orderly. Chromosomes are essential since they arrange the large amount of genetic material contained in eukaryote cells: if, for instance, the DNA contained in just one human somatic cell were unwrapped, the resulting molecule would be approximately two metres long! In bacteria, instead, the DNA is not contained in a nucleus and is round in shape. Another specific feature of bacteria is their protective structure (the wall) that enwraps and encloses the whole cell. The cellular wall is composed of proteins and sugars and, as well as protecting the micro-organism, it puts the cell in contact with the external environment and the other bacterial cells.

Many shapes for bacteria

Bacteria are classed by shape, feeding method, metabolism and wall features. Different forms of cells can be observed under the microscope. Cocci (from the Greek berries) are round in shape; when clustered together, they are called staphylococci, while when gathered into chains they are called streptococci. Rod-like prokaryotes are called bacilli. Bacilli can usually be found as separate cells, but sometimes they can be found in pairs (diplobacilli) or chains (streptobacilli). Other bacteria are bent in shape or look like a squat spiral. The former are called vibriones, while the latter are called spirilla. Finally, bacteria that look like a long and flexible spiral are called spirochetes. Spirochetes include some “giant” bacteria that can be up to 0.5 mm long, i.e. 500 times bigger than an ordinary prokaryote cell.

Autotrophic or eterotrophic bacteria

Depending on the way they take the two essential resources for their survival, energy and carbon (which they need for synthesising organic substances), bacteria can be classed as autotrophic or heterotrophic. **Autotrophic** prokaryotes can synthesise organic molecules from inorganic molecules, such as carbon dioxide. The energy needed for the synthesis can be supplied by light or other chemicals. The bacteria that, like plants, use solar energy are called **photoautotrophic**, while those that take energy from chemical reactions are called chemoautotrophic. Bacteria that need to feed on already synthesised organic molecules, as all animals do, are called **heterotrophic**. These bacteria can feed on virtually anything.

Some need oxygen, other do not

The word **metabolism** refers to those biochemical reactions that are vital for life and continuously occur inside the cells of each living being. Some of these reactions can only occur if there is oxygen. Some others, instead, do not need it. **Aerobic** bacteria are those bacteria that, like animals, “breathe oxygen”. **Anaerobic** bacteria are those bacteria that can live in an environment without this gas. Bacterial reproduction is asexual: it occurs by fission and not through the exchange of genetic material between two individuals of a different sex. Each bacterial cell divides itself to originate two identical cells that, in their turn, divide themselves into two other identical cells, and so on. A single cell is able to generate, in a short time, colonies of bacteria that are be made up of millions of cells.

Nitrogen fixers

Nitrogen is important for all organisms since it is one of the components of proteins and nucleic acids (DNA). Most living species cannot directly absorb nitrogen from the atmosphere, of which this gas is the largest component (78%). Only some bacteria can transform gaseous nitrogen into compounds that can be absorbed by the other living beings (especially vegetal organisms) through a series of metabolic reactions that are jointly called “nitrogen fixation”. Nitrogen, included in more complex molecules, such as ammonia and nitrates, is part of the food chain. The most important nitrogen-fixing organisms are *cyanobacteria*, also known as blue algae, which live in water. On the mainland, this function is mainly served by the *Azotobacte*r that live son earth and by the *Rhizobium* that lives in symbiosis in the roots of the plants of the genus *Leguminosae* (bean, lentil and clover).

Decomposers

Bacteria are among the main decomposing organisms, i.e. they degrade organic substances and release in the environment simple molecules that can be used by the other living beings. They play an essential role: without decomposers, the substances that make life possible would no longer be available in the environment. Some bacteria, the nitrifying ones, demolish proteins and release nitrogen-rich compounds, others release phosphor, sulphur and other useful substances.

Bacteria and digestion

The human gastrointestinal apparatus can contain on average 300-500 different species of bacteria that are jointly referred to as the “intestinal bacterial flora”. Most bacteria are located in the colon, while very few are in the stomach and in the first part of the intestine, because they contain corrosive substances (acids, bile and pancreatic secretions) which make these habitats inhospitable for micro-organisms. The colonisation of the intestine starts at birth and takes a few days. The bacterial flora is composed of anaerobic and aerobic bacteria. The first group includes such bacteria as bifidobacteria, eubacteria, clostridia and peptococci. Anaerobic bacteria include, among others, escherichia, enterobacteria, enterococci, klebsiella, lactobacilli and proteus. The intestinal bacterial flora serves different important functions:

- it protects the organisms from the attack of harmful micro-organisms;
- it breaks food into microscopic particles to supply the organism with vitamins, mineral salts and all the micro-nutrients it needs;
- it produces vitamin K, which is important for blood coagulation, the liver and bone calcification-it produces vitamin B12, which is important for cell reproduction and the synthesis of haemoglobin;
- it makes hard-to-digest foods, such as vegetables, digestible.

The bacterial flora of the intestine is weakened by some drugs, such as antibiotics. This is why antibiotic treatments are often associated with milk enzymes (which are among the main components of the bacterial flora), which restore the correct balance of these small and precious allies.

The bacteria of the rumen

Herbivores cannot directly absorb the vegetables they feed on, but they can through the action of the bacteria that colonise their digestive apparatus. Cattle chew vegetables for a long time and accumulate them in large amounts in the rumen, which is the first part of their stomach. In this hot, very humid place, bacteria quickly develop and attack the vegetal fibres. In so doing, the bacteria release the nutrients contained in these vegetables, which are then absorbed by the intestine. Horses do not have a rumen, but they host these precious bacteria in their long intestine.

Anywhere in the world

Bacteria live anywhere, even in the most extreme environments where no other form of life could survive. They can be found in the ocean depths, in the desert, in the hot waters of volcanic springs, inside rocks, in the frosty soil of the permafrost and even in environments so acidic they could destroy any other form of life. Many bacterial species live inside or on other organisms as symbionts or parasites. Symbiosis is an association between two or more species, which benefits each component; conversely, in parasitism only one of the members benefits from the association (the parasite), while the other (the host) is damaged by it. Our body too is inhabited by very many species of bacteria. Every square centimetre of our skin is populated by thousands

of bacterial cells that reproduce endlessly. Our gastrointestinal apparatus contains up to 500 different bacterial species, mostly living in the colon.

The first organisms

Bacteria have been the very first organisms to live on Earth. They made their appearance 3 billion years ago in the waters of the first oceans. At first, there were only anaerobic heterotrophic bacteria (the primordial atmosphere was virtually oxygen-free). The first autotrophic bacteria, very similar to the current cyanobacteria, appeared approximately 2 billion years ago. Photosynthesis occurred in these organisms and this is how the atmosphere was enriched with precious oxygen. Cyanobacteria or blue algae made the primitive atmosphere breathable and allowed life to colonise the lands above sea level. Man has just recently become aware of the existence of bacteria because they were too small to be observed or studied before the microscope was invented.

Man and bacteria

The first scientist to have studied and described bacteria was Anton van Leeuwenhoek (1632-1723). He was a textile dealer who lived in Holland ad used magnifying glasses to assess the quality of fabrics. In 1668, during a business trip to England, he bought some very powerful magnifying glasses with which he built a rudimentary microscope. His curiosity led him to observe a bit of everything and this is how he happened to see microbes for the very first time. In his writings, van Leeuwenhoek described bacteria as strange round-shaped beings. At first, there were many problems classing these new organisms since they were so peculiar they could not be included in either group of the living kingdoms: the vegetal and the animal kingdom. One century after van Leeuwenhoek, Carolus Linnaeus designed a new kingdom to include all the known micro-organisms that he called chaos.

The discovery of fermented bacteria

One of the main pioneers of microbiology was the French Louis Pasteur, who in 1854 was urged by spirit-makers to study fermentation. Pasteur proved that micro-organisms play an essential role in fermentation processes. In addition, he found that the unwanted reproduction of some substances, such as lactic acid or acetic acid, in spirits, is due to the presence of different kinds of micro-organisms, including bacteria. These discoveries helped develop the first effective troy harmful micro systems to destroy harmful micro-organisms. The term “microbe” was coined in 1878 by Charles Emmanuel Sédillot who, at the French Academy of Sciences, proposed that all microscopic organisms should be called microbes.

Bacteria, diseases and antibiotics

Not all bacteria are useful or harmless; some of them transmit diseases, even very serious ones, that especially in the past caused great epidemics. The bacterial origin of some pathologies, such

as the plague, cholera, pneumonia or meningitis, has been only recently discovered. In the past, when the existence of bacteria was not known, these diseases were thought to be caused by sorcery, curses or the influence of the stars. The discovery of the existence of pathogenic micro-organisms led research to find ways to fight them. In 1929, Alexander Fleming, a Scottish doctor who conducted researches at St. Mary's Hospital in London, discovered penicillin: the very first antibiotic substance ever known and studied. Penicillin was discovered by chance during some research on staphylococci. Fleming prepared some containers (plates) where he grew colonies of this micro-organism. To be observed, the plates had to be opened, exposing the bacterial cultures to the air, letting other micro-organisms in. So, some mildews started growing amongst the colonies of staphylococci. The scientist noticed that around the mildew the colonies grew more and more transparent until they disappeared, so he assumed that the mildew produced a substance that could wipe out the bacteria. Fleming extensively studied this substance and, since it was produced by the mildews of the genus Penicillium, he called it penicillin. The discovery of antibiotics has eradicated or remarkably reduced very many of the most dangerous diseases. But defeating bacteria is no easy feat. These micro-organisms can generate resistant strains, i.e. genetic variants that spontaneously evolve from one species and can survive even in the presence of antibiotic substances. This is why research must keep developing new antibiotics.

Bacteria and food

Man has been using bacteria for thousands of years, but he has only recently become aware of such uses. Very many foods are made with the aid of bacteria. These micro-organisms modify raw foods and transform them into new products with different chemical, physical, sensory and nutritional characteristics. In addition, these foods have a longer shelf life and sometimes they are even safer to use. Cheese, yoghurt, bread, wine, even dressed pork products and preserves are made with the aid of different species of bacteria.

Dairy farming

Milk bacteria, such as *Streptococcus thermophilus*and *Lactobacillus bulgaricus*, are the micro-organisms most commonly used in dairy farming. These bacteria, which come in the form of bacilli or cocci, are anaerobic (they do not need oxygen to survive) and transform simple sugars (glucose and lactose) into lactic acid through a metabolic process which is known as fermentation. Lactic acid alters the chemical and physical features of milk, transforming it into something else: yoghurt. Butter-making also needs the aid of some micro-organisms: the typical taste of this product is due to the presence of diacetyl, a substance released by the milk bacteria that develop as the milk cream ages. Some bacteria can produce substances, such as bacteriocins and nisins, that have an antibiotic effect, i.e. they fight the harmful bacteria that could contaminate cheese. Special bacteria, known as “proponic”, develop in some types of cheese, such as Emmenthal and Gruyère, and produce large amounts of carbon dioxide. The gas forms gaps in the cheese paste which when aged exhibits the famous “holes”.

Bacteria with a good taste

Milk bacteria are also used to make many baked products, such as brioches, cakes and biscuits. With the aid of bacteria, these foods acquire a better flavour and taste. Wine, especially red wine submitted to ageing processes, is also made with the aid of some bacteria that, by transforming malic acid into lactic acid, improve the taste of wine. Dressed pork products are made with the aid of some bacteria of the genera Lactobacillus, Pediococcus and organisms produce antibacterial substances that give these products a longer shelf life and Micrococcus. These micro-organisms produce antibacterial substances that give these products a longer shelf life and release molecules that improve their taste. Micrococci in particular transform the fats and cure the pork meat.

Pasteurization

The presence of bacteria in some foods is undesirable since it speeds up decomposition and could be dangerous for human health. The oldest method developed to control the concentration of bacteria in food was invented by Louis Pasteur in the late 19th century, and this is why it is known as pasteurisation. It is a process that reduces the amount of bacteria without altering the nutritional and sensory features of the food. This process consists in heating the product for a few minutes at 55C° to 70C°. In this way, a large part of the bacteria dies, thus making the food more hygienic. Today, milk, sauces, creams, preserves and beer are commonly pasteurised before being sold.

Let's cure ourselves with bacteria

Bacteria are used to make a high number of pharmacologically important substances. *Actinomycetes*, for instance, are thread-like bacteria that morphologically resemble mildews. They are among the most important producers of antibiotics, such as streptomycin and tetracycline. Vitamin B12 (cobalamin) is also produced in laboratory by bacteria. Some special bacterial strains are used as test micro-organisms to determine the antibiotic and vitamin content of some foods or drugs. Microbial strain means a bacterium that, although belonging to a given species, has distinctive morphological and metabolic features, such as, for instance, specific resistance to antibiotics, production of some substances or resistance to specific environmental conditions. A bacterial colony is instead a cluster of cells that is visible to the naked eye, mostly round in shape, and is originated by the proliferation of strains. A colony consists therefore of a very high number of bacteria from the same strain.

Biotechnology

Through biotechnology, segments of DNA can be introduced in the genetic inheritance of a bacterium. Human DNA supplies bacterial cells with instructions to synthesise proteins that the bacteria usually do not synthesise. This has led to the production of proteins that are very important to treat some diseases. Nowadays, substances that in the past used to be extracted from natural sources and often available in limited amounts can be obtained from bacteria in

large amounts and at low costs. The protein molecules of bacterial origin that are useful in medicine include insulin for diabetes, interferon for viral infections and the growth hormone.

Environment

A group of American scientists have succeeded to create some genetically modified organisms that can produce oil. The most popular biological fuel nowadays in the United States is ethanol, which is obtained mainly from corn, but this new technology could replace it. In fact, ethanol has only two thirds of the energetic power of oil and it takes a lot of resources to produce. Instead, oil from microorganisms requires only minor infrastructure investments but further studies are needed before starting this kind of production. American scientists have thought of taking pieces of DNA which are responsible for the conversion cycle of glucose into energy storage molecules from different organisms and then combine this genetic material and insert it into a microorganism to give it instructions to produce hydrocarbons. Other microorganism genes have been modified so as to block other metabolic functions so that they will concentrate on oil production. Scientists have discovered a way to alter parts of DNA sequencing to increase oil production, but so far the output is still too low. One of the weak points in this production is the source of cellulose with which to feed the microorganisms and they hope that soon they will be able to find a cheaper and more efficient one.

Energy production

Some bacterial strains of the genus Zymomonas can transform sugar into ethanol, the same alcohol that can be found in wine and beer. The ethanol obtained from these bacteria is mixed with petrol to make fuel. This process is used in particular in hot countries, where sugary substances, such as sugarcane, are extensively produced. Methane too can be produced with the aid of bacteria. Methanogen bacteria take their name from their ability to produce gas by fermenting organic substances, such as animal faeces and waste. This ability is exploited to produce biogas for heating or cooking.

Bacteria against pollution

Pseudomonas are aerobic, rod-shaped bacteria. They can use over one hundred organic compounds as a source of energy and carbon. Because of this, some strains have been used to remove highly polluting, hard-to-degrade compounds, such as some components of oil, fungicides, pesticides and herbicides. Research is testing several methods to use these bacteria in ecological disasters caused by oil leaks from tankers. In particular, strains are being selected in an attempt to find those that are able to feed on oil. These micro-organisms break up the masses of crude oil that float on the water or soil the beaches and destroy them through digestion.

Genetically modified poplars

Some University of Seattle scientists have created a poplar which, with its roots, can remove certain industrial pollutants such as trichloroethylene from the soil. By modifying the poplar's DNA, the tree becomes able to clean the soil and the environment in general from toxins. To perform this experiment, scientists have added to the poplar's DNA a gene which codifies certain enzymes that are found in mammals.

Biological fight

Some insects, fungi and protozoa are the most important organisms that can damage man and man's activities. Nevertheless, even harmful organisms can be affected by diseases, many of which are transmitted by bacteria. These bacteria can be used to get rid of those organisms that can damage farming, forests, animals' and man's health. The Bacillus thuringensis, for instance, is a bacterium used in agriculture and forestry to fight the grubs of many butterflies, which are responsible for the destruction of the foliage. A watery solution containing these bacteria is sprayed onto the plants. As they eat the leaves, the grubs become infected with these bacteria and die in a few hours. These organic fighting techniques are very selective, since the bacteria used in these methods attack harmful organisms only.

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