

UNIVERSITY OF TLEMCEN  
FACULTY OF NATURAL AND LIFE SCIENCES AND EARTH AND UNIVERSE SCIENCES  
DEPARTMENT OF AGRONOMY  
FOOD SCIENCE  
AGRI-FOOD INDUSTRY TECHNOLOGY



# Food biotechnology

**Fatima Zahra Ghanemi**

---

**Course intended for students of**  
*Bachelor's degree (L3) in Food Industry Technology, specializing in Food Science*

2026

# FOOD BIOTECHNOLOGY

Fatima Zahra Ghanemi

Published in Tlemcen, Algeria



**Food biotechnology**

**Fatima Zahra Ghanemi**

**© Ghanemi FZ, University of Tlemcen, 2026**

## **Summary**

This handout highlights biotechnological advances and approaches aimed at improving the nutritional value of agri-food products. These three chapters help to better understand food biotechnology in order to optimize food production and extend its shelf life, while also improving its nutritional quality by transforming simple substrates into valuable metabolites and effectively addressing waste and pollution issues.

Written and prepared based on scientific books and articles in the field of food biotechnology, this handout offers simplified, reliable, and detailed information on technological advances, fundamental principles, and applications of recent innovations. It thus guides postgraduate students in the field of agri-food technology in their learning and future research.

---

## **Preface**

Biotechnology is about harnessing life's full potential. This science is characterized by its interdisciplinary nature. Depending on the research focus, a wide range of knowledge is essential, encompassing general biology, agronomy, human genetics, molecular biology, pharmaceuticals, and immunology. This course material covers a diverse range of topics, from the production of yogurt and cheese to genetically modified organisms and the manufacture of drugs such as insulin. This information has been presented comprehensively, with illustrations throughout to facilitate student understanding and assimilation of the material.

Biotechnology is one of the richest sciences that every student should explore, allowing them not only to expand their knowledge but also to open their minds to the development of new ideas and even to gain perspectives for future projects.

# Table of Contents

<b>Summary.....</b>	<b>iv</b>
<b>Preface .....</b>	<b>v</b>
<b>1. Introduction.....</b>	<b>1</b>
<b>2. Chapter 1 (Biotechnology) .....</b>	<b>2</b>
<b>2.1 History and evolution of biotechnology.....</b>	<b>2</b>
2.1.1 The beginnings of biotechnology.....	3
2.1.2 Early biotechnology (pre-1800) .....	4
2.1.3 Classical Biotechnology.....	3
2.1.4 Modern biotechnology .....	4
<b>2.2 The birth of modern biotechnology.....</b>	<b>5</b>
<b>2.3 The classes of biotechnology.....</b>	<b>7</b>
<b>2.4 Genetically modified organisms (GMOs) .....</b>	<b>11</b>
<b>2.5 Food biotechnology .....</b>	<b>12</b>
<b>3. Chapter 2 (Fermentation) .....</b>	<b>17</b>
3.1 Definition of fermentation.....	17
3.2 Types of microorganisms .....	17
3.2.1 The main types of fermentation .....	18
3.2.2 The main ferments.....	19
3.2.3 Bacteria.....	19
3.2.4 Molds.....	20
3.2.5 Yeasts .....	20
3.3. The fermenter .....	21
<b>4. Chapter 3 (Fermenters) .....</b>	<b>24</b>
4.1 Role of fermenters.....	24
4.2 Fermentation Stages .....	24
4.3 The fermenter, the heart of the process.....	24
4.4 Description of a fermenter .....	26
4.5 The history of bioreactors.....	26
4.6 Applications of the bioreactor.....	27
4.7 The different fermentation systems .....	28
<b>5. Conclusion .....</b>	<b>32</b>
<b>6. Revision .....</b>	<b>33</b>
<b>7. References .....</b>	<b>37</b>
<b>8. Bibliography.....</b>	<b>32</b>

## **1. Introduction**

Biotechnology is a multidisciplinary field that combines the capabilities of living organisms or their components with various techniques and methods for economic development. Currently, this science is considered one of the most innovative technologies, thanks to the significant advances in molecular biology over the past few decades.

Biotechnology, which involves the use of molecular and cellular tools to optimize and transform food production, will become increasingly crucial in the face of the ongoing challenge of providing enough food for a constantly growing global population. These methods will serve to enrich and refine conventional breeding techniques, while taking environmental issues into account and contributing to the stabilization of food production.

This field of study encompasses several disciplines, including agriculture, biochemistry, molecular biology, microbiology, genetics, and immunology, to name just a few. Each sector brings its own specific vocabulary, which can create significant communication and nomenclature problems.

## **2. Chapter 1 (Biotechnology)**

The term "biotechnology" is made up of two words:

The first part of the term Bio comes from the Greek word bios, meaning "life." The term's evolution in biology took place in the early 19th century. Naturally, the word technology derives from the Greek word "technologia." This term was introduced into French writing in 1656 to refer to the analysis of techniques, instruments, machines, and materials.

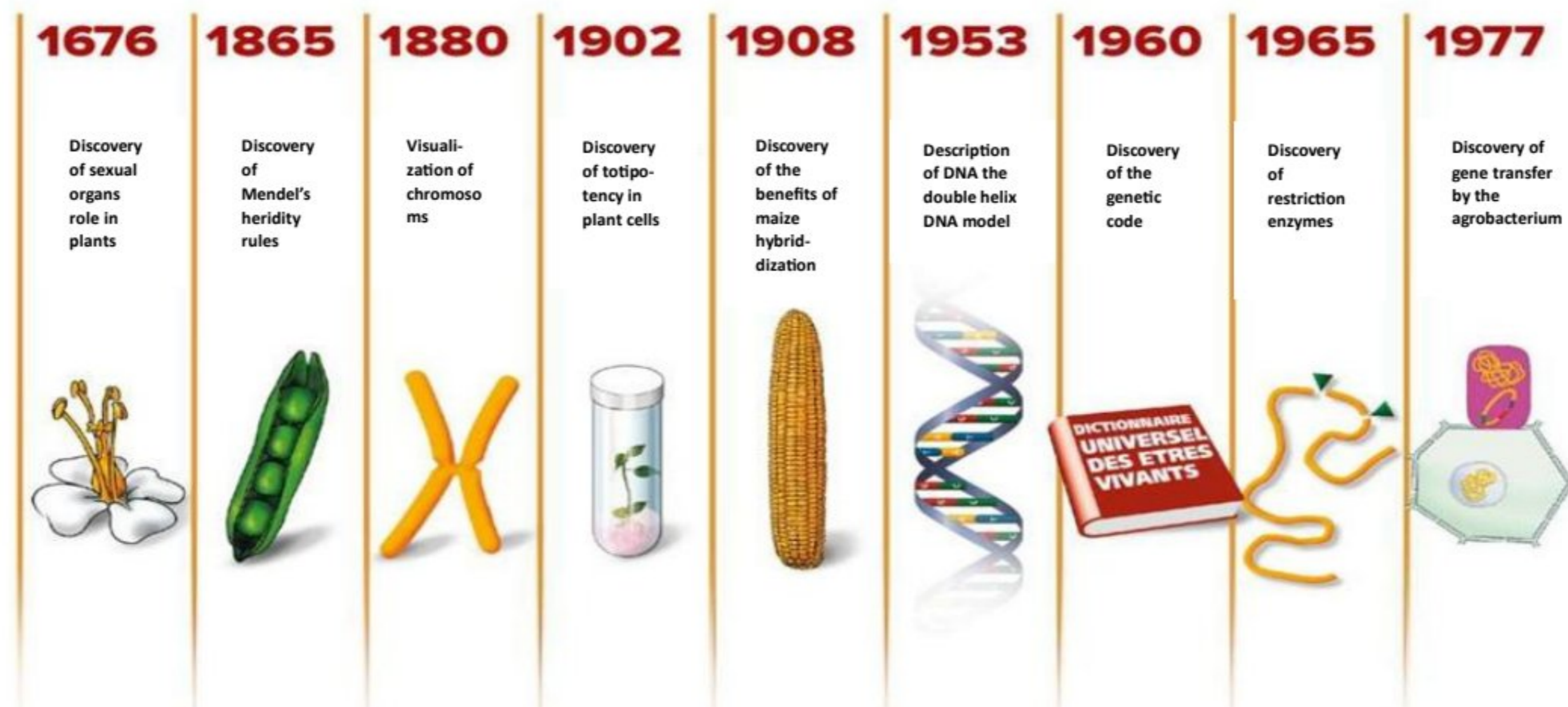
### **2.1 History and evolution of biotechnology**

The progression from the domestication of crops and animals from the earliest era (before the Common Era) to modern biotechnology methods in the 21st century is presented as follows:

- Old-era biotechnology (1st generation)
- Classical-era biotechnology (2nd generation)
- Modern-era biotechnology (3rd generation)

From antiquity (before our era) to the evolution of agriculture ([Figure 1](#)). The chronology of biotechnology has followed the following evolution:

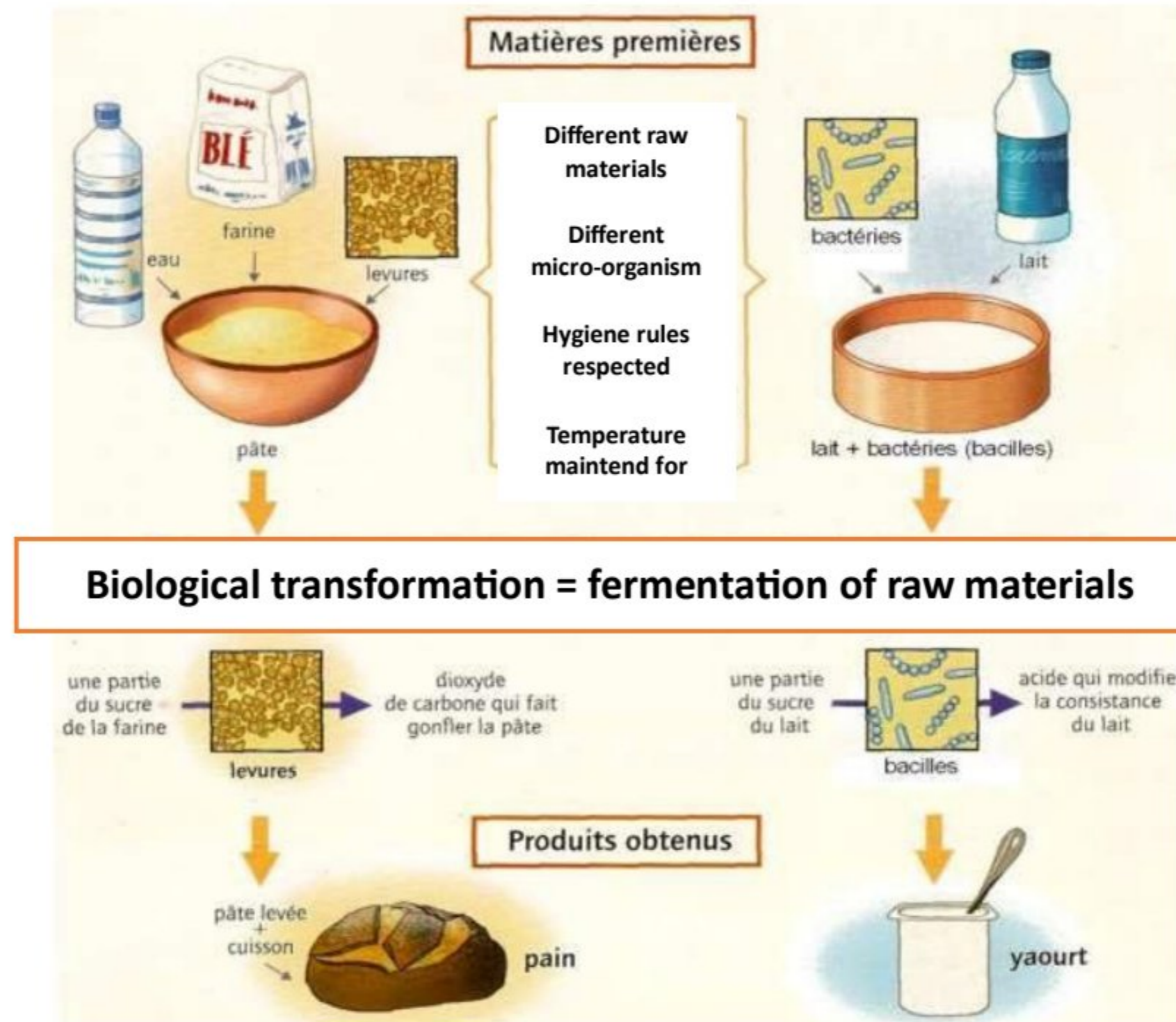
- 7000 BC: discovery of beer fermentation by the Chinese.
- 6000 BC: production of cheese and yogurt using lactic bacteria
- 4000 BC: fermentation of leavened bread with yeast by the Egyptians.
- 500 BC: use of an antibiotic made from molded soy curd
- 250 BC: Crop rotation by the Greeks to optimize soil fertility
- 100 BC: Chrysanthemum were used as natural insecticides by the Chinese



**Figure 1. The main historical landmarks in the evolution of biotechnology**

### 2.1.1 The beginnings of biotechnology

Biotechnology is recognized as a rather ancient science. Indeed, by pure coincidence and without knowing or understanding the fermentation process or the principles of genetics, humankind has been using certain biotechnological processes since antiquity, in the production of cheese, wine, bread, selective breeding of animals as well as selective cultivation of plants etc (Figure 2).



**Figure 2. Examples of fermented foods**

### 2.1.2 Traditional biotechnology (before the 19th century)

With the settling of humans, the history of fermented foods gradually emerged (9000 years BCE). The major distinguishing features of this era are:

- Through accidental discoveries of fermentation;
- A noticeably improved texture and taste of food;
- Bacteria and fungi are the cause of no-intentional contamination.

Furthermore, it is worth noting that Louis Pasteur was first praised in 1866 for publishing his discoveries concerning the direct link between sugar fermentation and the action of yeasts. In addition, during this period, the production of baker's yeast, *Saccharomyces cerevisiae*, was also observed.

### 2.1.3 Classical Biotechnology

This era is marked by the emergence of various kinds of fermented beverages such as beer, cider, wine, etc., as well as the production of vinegar, glycerin, acetone, butanol, lactic acid, and citric acid. Simultaneously, the appearance of therapeutic products derived from chemical transformations, such as antibiotics, was also observed (Figure 3).

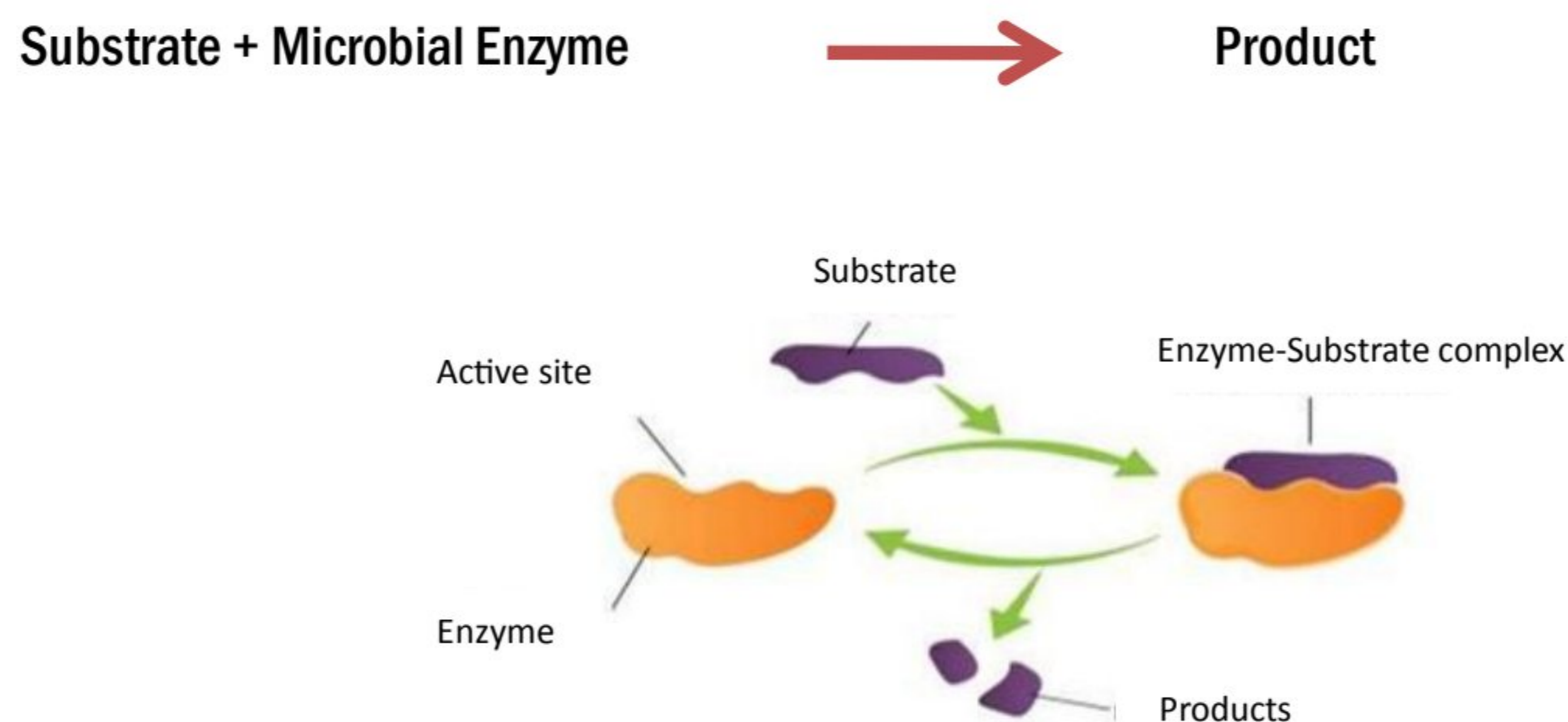
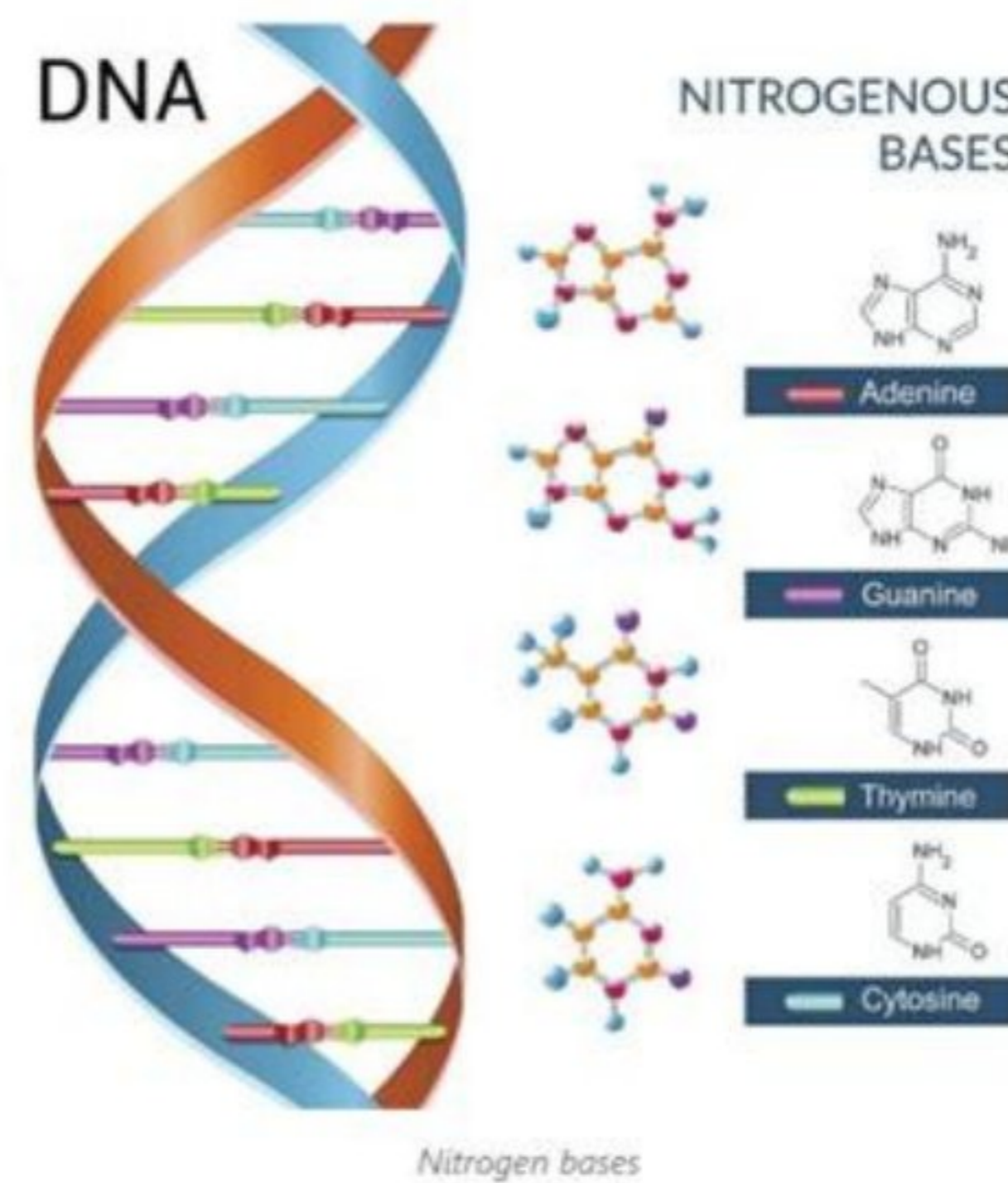


Figure 3. Mode of action of the substrate with the enzyme

### 2.1.4 Modern Biotechnology

Crick and Watson first revealed the mystery of DNA as the genetic carrier in 1953, with the presentation of their structural model of DNA strands under the name "DNA Double Helix" (Figure 4).



**Figure 4. Double helix model of DNA strands**

The contemporary appeal of biotechnology lies in the potential offered by combining biological processes and techniques (traditional and modern) with methods from chemical engineering and electronics.

Modern biotechnology could be illustrated as a tree whose roots symbolize biological sciences such as microbiology, genetics, molecular biology and biochemistry, and whose branches correspond to chemical process engineering in its broadest sense.

## 2.2 The birth of modern biotechnology

The emergence of modern biotechnology is linked to the discovery and evolution of methods for large-scale penicillin production.

During World War II, the demand for antibiotics increased sharply, stimulating the joint efforts of chemical engineers and microbiologists who attempted to mass-produce penicillin through fermentation techniques.



Subsequently, the industry modernized through biotechnology and set itself the goal of exploiting enzymes. These molecules are the true protagonists of bioreactions and constitute the active agents of microorganisms.

Unlike microorganisms, enzymes can be controlled in a way almost similar to a chemical molecule: they do not generate side reactions nor reproduce, which eliminates concerns related to biomass formation.

However, this factor can turn into a disadvantage, because generally, enzymes require coenzymes or mediators to function, and once inactivated, they lose their usefulness in bioreactions (Figure 5).

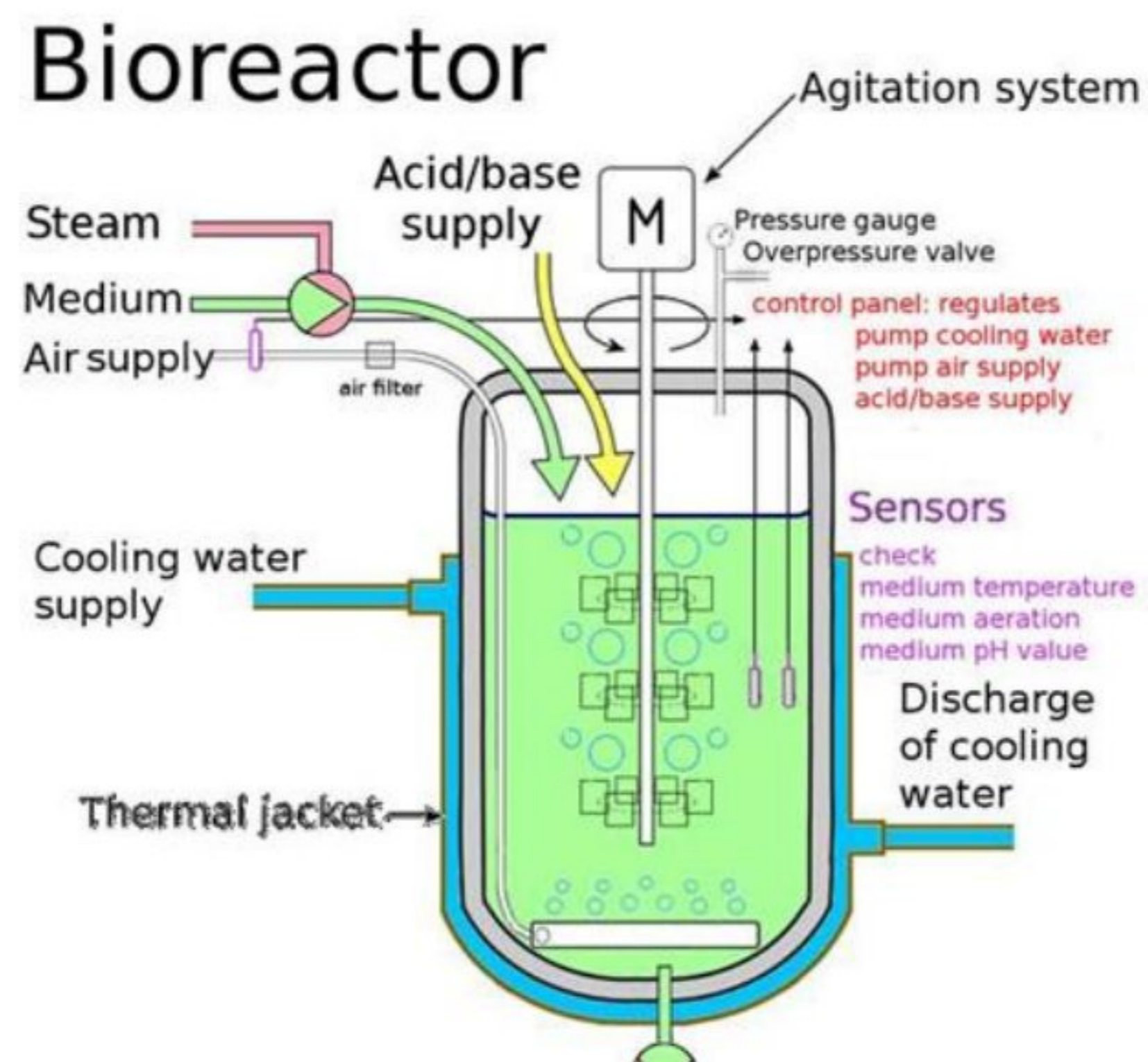


Figure 5. Diagram of a bioreactor

### 2.2.1 The first applications of modern biotechnology

The first applications of enzymes in the biotechnology sector involved the production of sweeteners (such as the extraction of fructose syrup from wheat) and the use of lipases and proteases in detergents to tackle stubborn stains.

The use of specific enzymes, usually derived from genetically modified microorganisms, gives rise to the second generation of industrial biotechnology (also called modern biotechnology), which already distinctly encompasses microbiology, biochemistry and process engineering.

### 2.2.2 The latest generation of biotechnology

Thus, the technologies included in the contemporary definition of biotechnology are as follows:

- Genetic engineering (recombinant DNA)
- Plant cell culture
- Mammalian cell culture
- Biological catalysts

- The exploitation and valorization of waste through biotechnological techniques (bioremediation)
- Fermentation reactions
- The production of organic fuels and raw materials through biotechnological methods, as a substitute for petroleum;
- Biotechnological process engineering

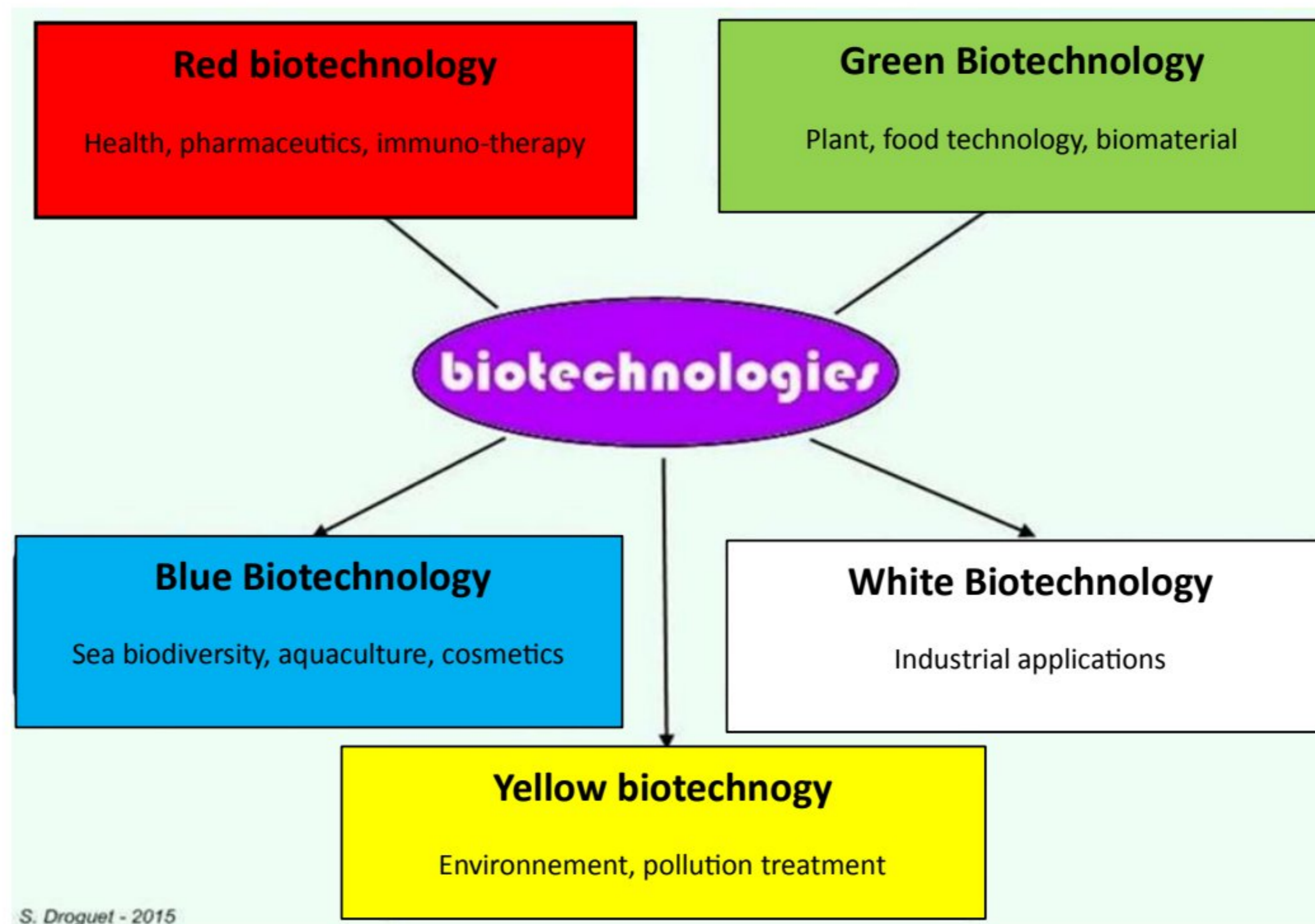
### **2.2.3 The benefits of biotechnology**

The entrepreneurial sector is implementing industrial biotechnology to:

- Reduce their expenses
- Increase their profits
- Improve the quality of their products
- Improve their procedure and its follow-up
- To improve their process and its monitoring
- Strengthening safety and hygiene related to technology
- Comply with environmental law

### **2.3 The classes of biotechnology (Figure 6).**

- White biotechnology: uses biological systems (bacteria);
- Yellow biotechnology: focuses on everything related to the environment (pollution);
- Red biotechnology: concerns human (biomedicine) and animal health, as well as the production of diseases;
- Blue biotechnology: draws on marine science.
- Green biotechnology: involves agricultural and agri-food production (GMOs), as well as fermentation using microorganisms to produce alcohol, cheese and acetic acid.



**Figure 6. The main classes of biotechnology**

### 2.3.1 Red biotechnology

This class includes, among other things, the manufacture of vaccines and antibiotics, the development of new treatments, molecular diagnostic methods, regenerative therapies and the advancement of genetic engineering, to treat pathologies through genetic manipulation.

Cell therapy and regenerative medicine, gene therapy, and treatments based on biological molecules such as therapeutic antibodies are significant examples of red biotechnology.

### 2.3.2 White biotechnology

White biotechnology focuses on creating resource-efficient processes and products, making them more environmentally friendly and less polluting than conventional methods. Specifically, it includes the use of microorganisms for chemical production, the design and development of new materials for everyday use such as textiles and plastics, and the creation of sustainable and innovative energy sources like biofuels.

### 2.3.3 Yellow biotechnology (also known as Grey biotechnology)

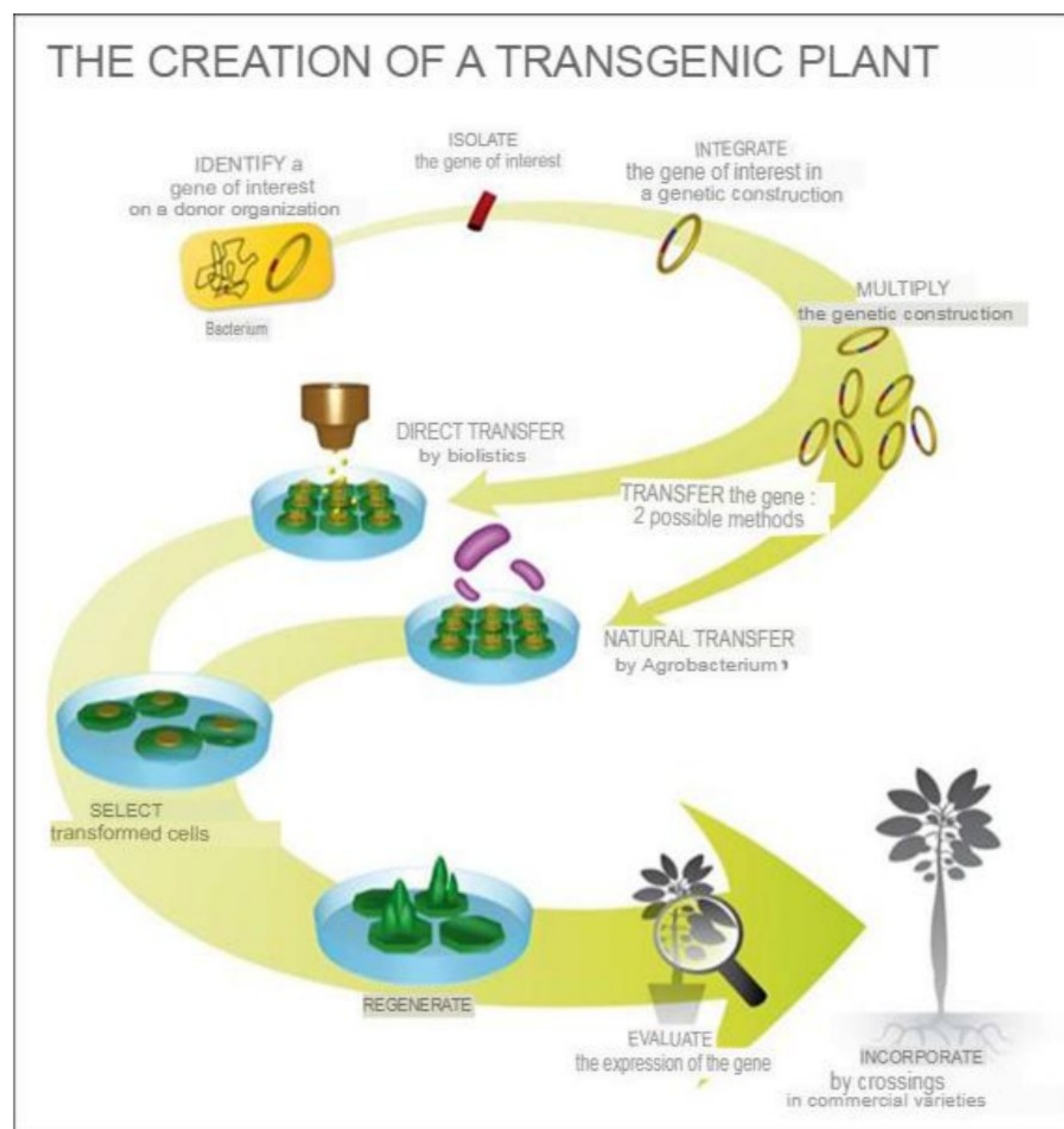
It focuses on the environment, but also on preserving biodiversity and eliminating pollutants. Regarding the first aspect, it is important to highlight the use of molecular biology to examine the genetics of populations and species that make up ecosystems, in order to compare and classify them.

Furthermore, cloning methods are widely used for the purpose of safeguarding species and genome conservation technologies.

Bioremediation, which concerns the elimination of pollutants, uses grey biotechnology, which uses microorganisms and plants to better identify or even remove various substances, such as heavy metals and hydrocarbons.

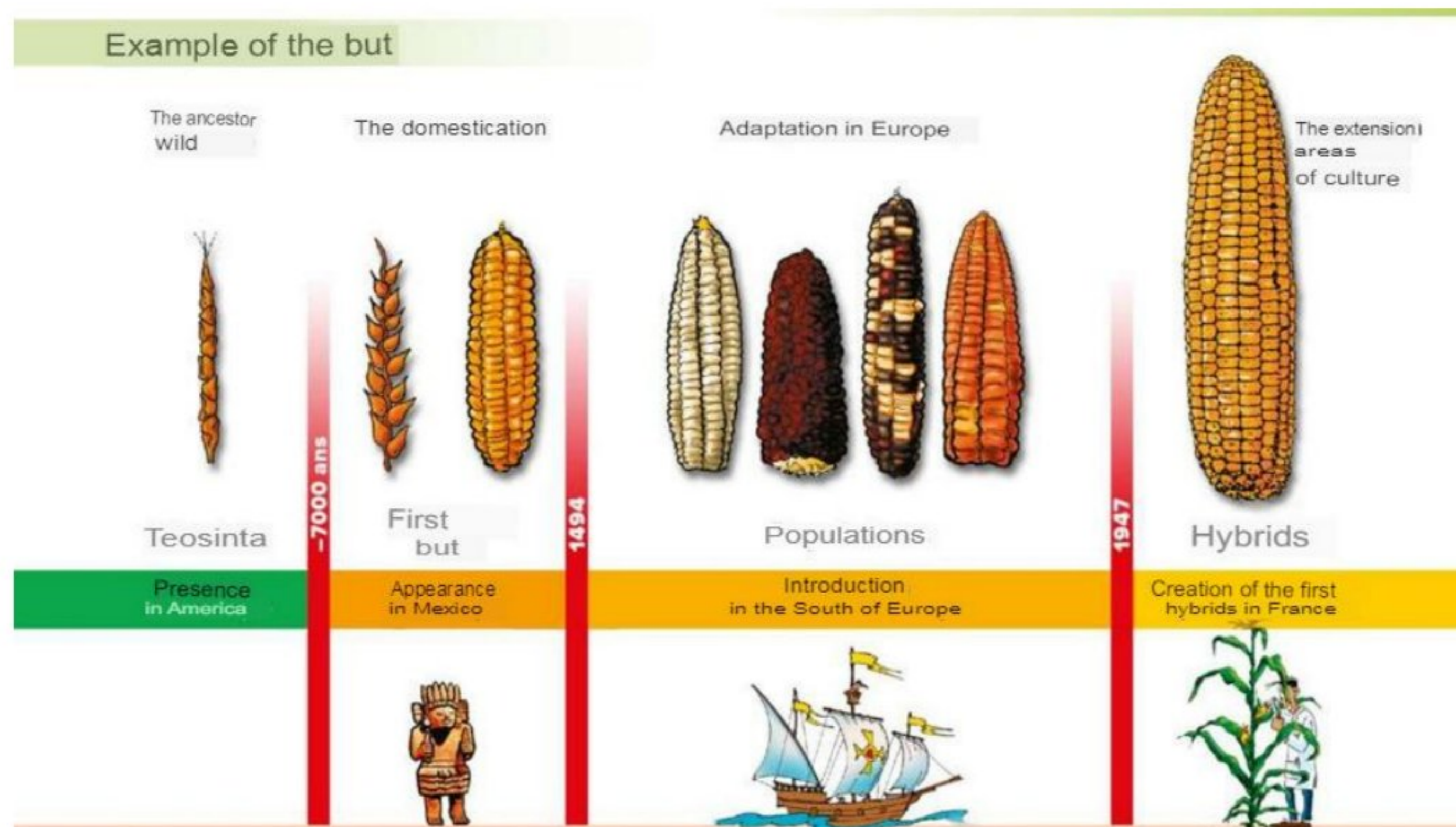
### 2.3.4 Green biotechnology

Agriculture is the primary application area of green biotechnology. Green biotechnology methodologies and applications encompass the design of new crop varieties, the production of biopesticides and biofertilizers, and the use of *in vitro* culture and cloning plants. (Figure 7).



**Figure 7. Creation of a transgenic plant**

This first approach generates the most interest and social debate. The cultivation of genetically modified plant traits is carried out almost exclusively through transgenesis, which involves inserting genes specific to another variety or organism into the plant (Figure 8).



**Figure 8. Evolution of the corn ear over time**

This technology aims to achieve three main objectives:

- Varieties resistant to infestations and diseases, such as the maize varieties currently in use on the market that are resistant to the European corn borer;
- Genetically modified plants intended to create varieties with superior nutritional characteristics (e.g., a more satisfactory dietary vitamin content);
- Plant species capable of functioning as bio-factories and producing compounds of medical, biomedical or industrial interest in easily isolable and purifiable volumes.

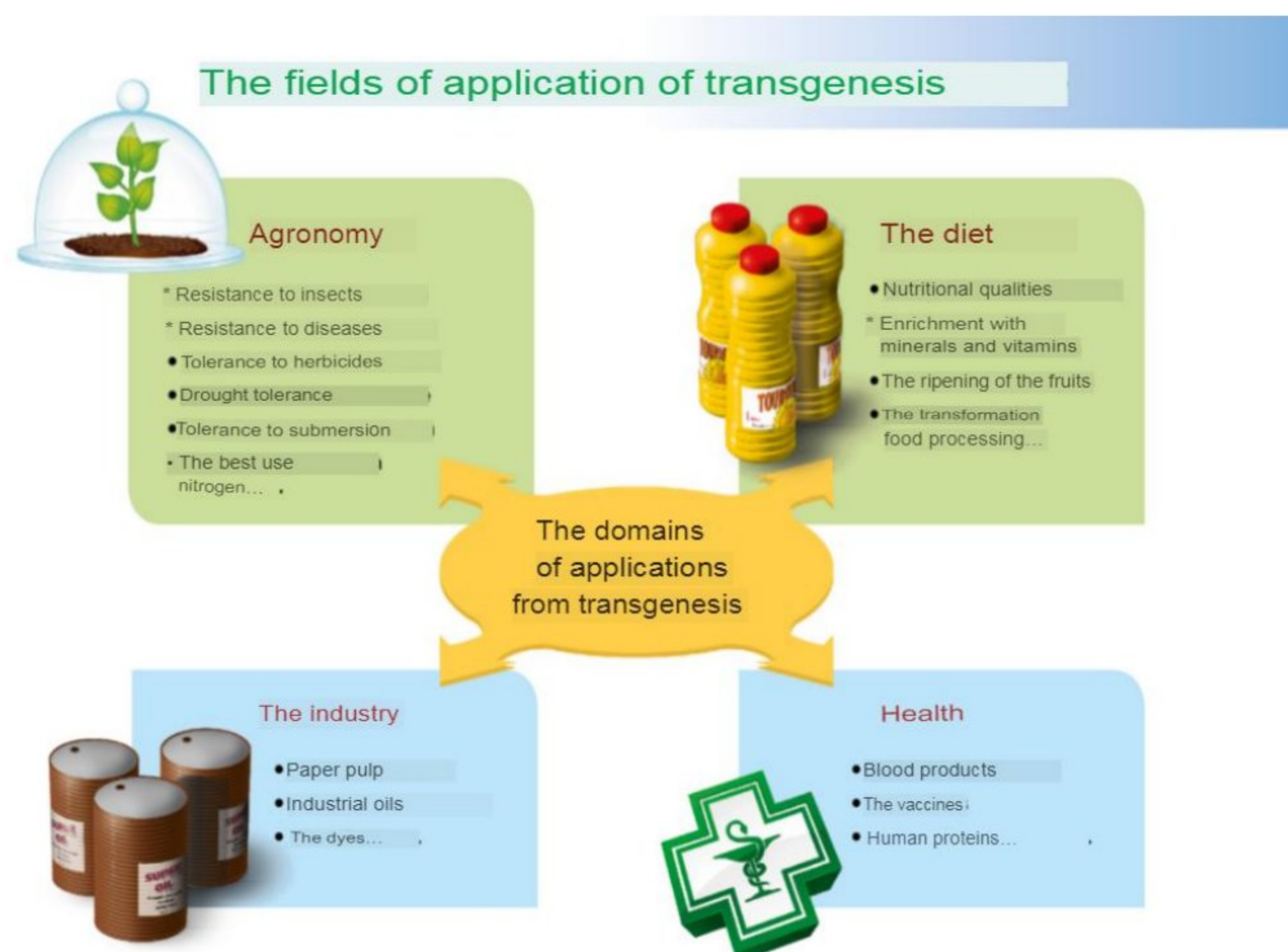
### 2.3.5 Blue Biotechnology

The marine ecosystem represents an untapped source of active biological components with enormous potential for the development of functional foods. To increase the availability and chemical diversity of these ingredients, several studies based on biotechnological techniques have been conducted with the aim of creating and producing new compounds.

These elements, which mainly include hydrocolloids and gelling agents, are already widely used in the food, health, and processing sectors, among others.

Marine biotechnology is also of great use in medicine and research. In research, the use of indicator molecules derived from marine organisms is now commonplace.

Active enzymatic molecules, useful for diagnostics and research, have also been isolated from marine organisms. Certain biomaterials, pharmacological agents, or regenerative agents for use in these various sectors are being manufactured or analyzed. Ultimately, sectors such as agriculture and the cosmetics industry are exploring the prospects that marine biotechnology offers for future development. (Figure 9).



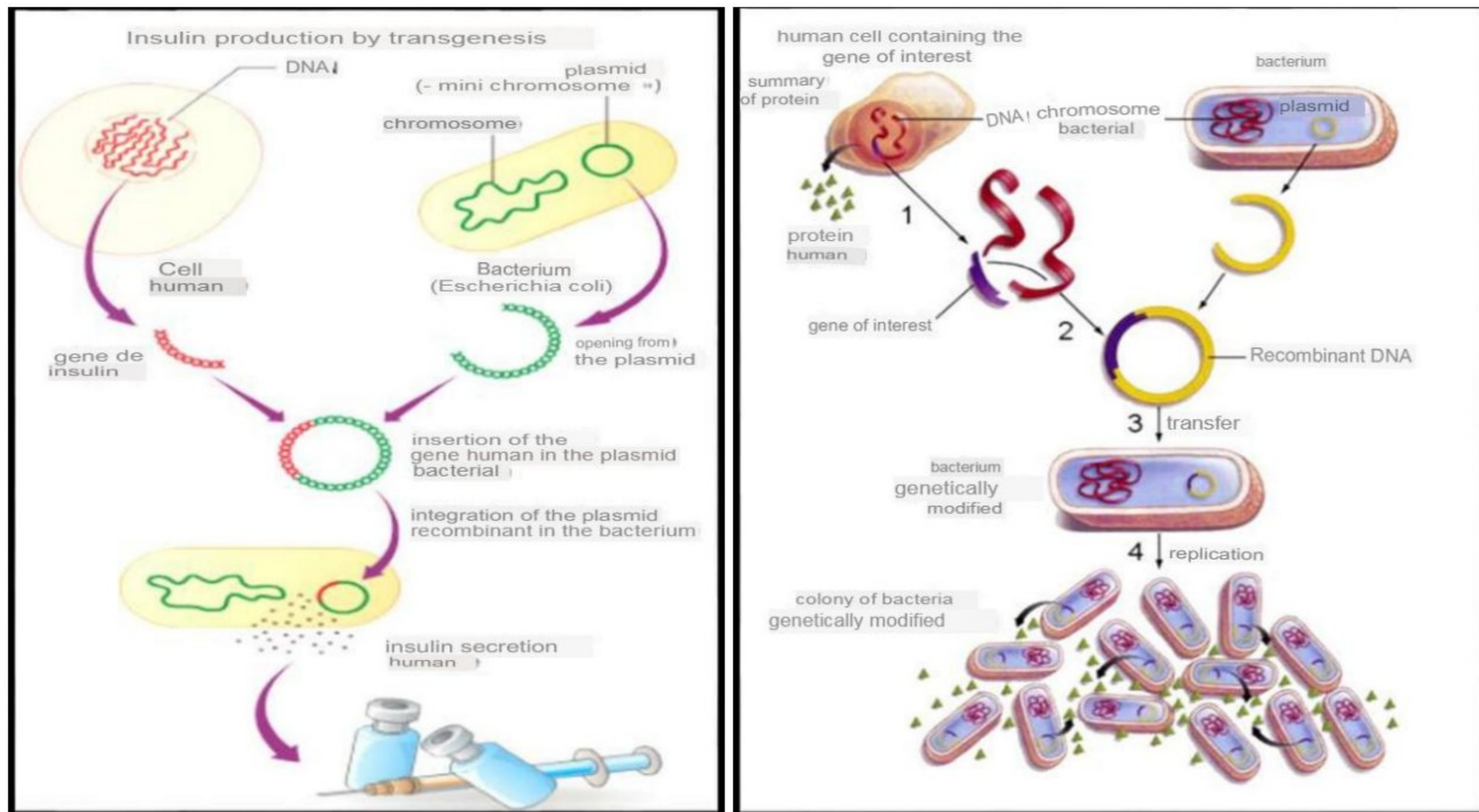
**Figure 9. Application areas of transgenesis**

## 2.4 Genetically modified organisms (GMOs)

GMOs are one of the many products of modern agricultural biotechnology. They are living organisms whose genetic makeup has been modified by the insertion of a foreign gene. This is a conventional method of genetic improvement.

Nowadays, it is possible to extract, isolate, sequence, cut, paste, transfer, and recombine DNA. One method of genome editing is called transgenesis. New insecticidal proteins are also being developed, offering the advantage of broad-spectrum control of lepidopteran pests throughout the season, thus reducing the number of insecticide treatments required.

An example of a commonly used genetically modified product is insulin (Figure 10). It is used in the treatment of diabetes. Previously, it was extracted from pig pancreas. Today, the human insulin gene is being cloned into bacteria. The multiplication of the bacteria allows for a significant production of insulin, which is then purified.



**Figure 10. Examples of insulin and protein of interest production**

## 2.5 Food biotechnology

Food biotechnology involves applying traditional and modern technologies, using systems of microbial, plant or animal origin to improve the production, processing and distribution of healthy, nutritious, tasty and inexpensive food.

### 2.5.1 The advantages of food biotechnology

The advantages of food biotechnology are numerous:

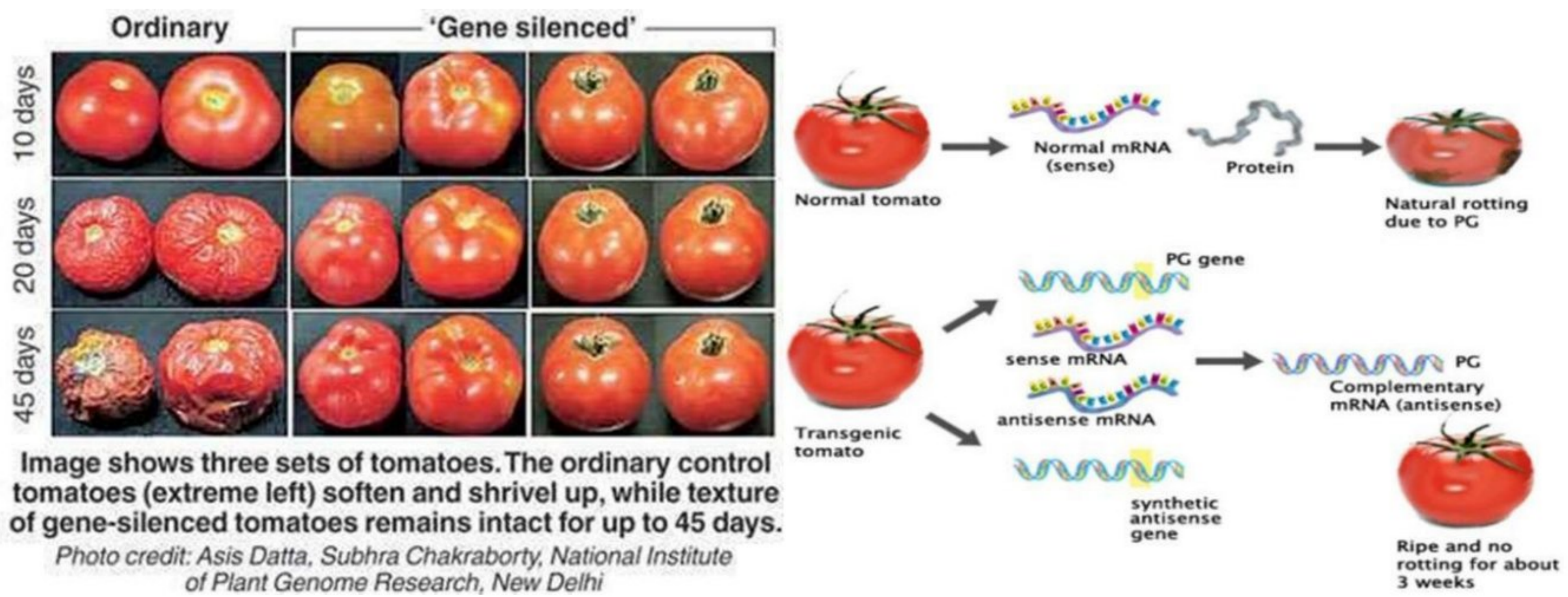
- Improved crop yields thanks to enhanced herbicide tolerance and resistance to pests and diseases.

Examples: plants that tolerate sprayed herbicides to eliminate weeds. Plants that act like pesticides, such as the Nature Mark® potato, which repels the Colorado potato beetle and is safe for animals and humans (Figure 11).



**Figure 11. The Colorado potato beetle**

- An improvement in the taste of food, as in the case of the Flavor Savor (MD) tomato, which has an improved flavor and a longer shelf life (Figure 12);



**Figure 12. PG (Polygalacturonase), the enzyme that degrades the cell wall of the tomato fruit**

- Cold tolerance: plants are bred to withstand low temperatures and unexpected frost that could destroy the seeds (Figure 13);

- Tolerance to drought and salinity: we now cultivate in arid regions.

- Improved nutrient content: Rice is a staple food in developing countries, but it is not a complete food. Golden rice (a genetically modified food) has a high beta-carotene (vitamin A) content (Figure 13).



**Figure 13. Improved nutrient content and cold resistance through biotechnology**

- Technological additives, such as renin, are used in cheesemaking as a replacement for rennet extracted from the abomasum of young ruminants. The advantages of renin are: purity, consistent supply, and reduced costs (Figure 14).



**Figure 14. Example of coagulating enzyme synthesis for cheese making**

### 2.5.2 The challenges of food biotechnology

\*Environmental challenges:

- Unintentional damage caused to other organisms; there is indeed a risk of harming non-target organisms, as in the case of a pest-resistant crop that produces toxins affecting both harmful insects and beneficial insects.
- Reduced effectiveness of pesticides as pest resistance to modified crops increases.
- The transfer of genes to non-target species, for example in the case of plants with herbicide tolerance that cross with weeds, which could create herbicide-resistant weeds.

\*Risks to human health: allergenicity.

- Economic concerns: significant resources are being devoted to the creation of modified crops and companies are obtaining patents for these new plants; some are concerned that such patenting will cause seed prices to rise, thus limiting access for small farms and developing countries.

Mandatory labeling of genetically modified foods could prove costly and difficult to implement, and its disadvantages could outweigh its benefits, for consumers. The question is whether or not only to label genetically modified foods, but also how to cost-effectively provide consumers with useful information.

### **2.5.3 Impact of biotechnology on the food industry**

a) Agronomic advantages: Improved yields, development of hybrids and resistant plant varieties through the application of cellular and molecular genetics tools.

b) Non-agronomic advantages

The application of biotechnological processes that promote the development of new plants improves unit operations and reduces the price of manufactured products, thereby enhancing product competitiveness.

• Despite their effects on nutritional quality, biological processes were not previously considered unit operations. The application of these processes takes various forms:

- Enzymatic treatment,
- Fermentation and its influences,
- Germination,
- Plant tissue culture, etc.

a) Enzyme treatment

This process is used in the production of fruit and vegetable juices. It increases yield and content of carotene, while reducing the content of antinutritional compounds.

b) Fermentation and its influences

In addition to its preservative power, fermentation also influences texture, flavor, and nutritional quality.

- Influence of fermentation on protein and amino acid content

The effects vary depending on the type of microorganisms used, but it's important to remember that fermentation does not alter the protein content. However, it does lead to an increase in the free amino acid content.

- Influence of fermentation on lipid content: although the use of microorganisms during fermentation does not lead to a change in the total lipid content, an increase in the free fatty acid content is observed.

- Influence of fermentation on vitamin content: depending on the microorganisms used, the effects are different; - the vitamin B1 content generally decreases, while the vitamin B2 and niacin content increases in cereals;

- The content of vitamins B6 and B12 increases in cereal oils.

- Influence of fermentation on antinutritional compounds: fermentation helps to reduce the content of antinutritional compounds such as phytate, gossypol, goitrogenic, carcinogenic and mutagenic substances.

c) Germination: it allows the production of plant products with increased protein, lysine, and vitamin content. It also allows the reduction or elimination of certain substances.

d) Plant tissue culture: this technique, combined with traditional and biological methods, aims to improve the quality of raw materials and food. Based on strain selection, it makes it possible to obtain products with predefined characteristics.

- The large-scale production of chemical substances previously produced from petroleum, including ethanol, butanol, acetone, acetic acid, etc.

### **3. Chapter 2 (Fermentation)**

Fermentation is carried out by anaerobic microorganisms capable of breaking down organic matter (carbohydrates, lipids and proteins) into organic acids and alcohols, and producing methane and carbon dioxide, depending on the type of fermentation.

- The fermentation reaction does not involve oxygen; it therefore takes place in the absence of air, this reaction therefore takes place in anaerobic conditions.

#### **3.1 Definition of fermentation**

Fermentations are biological reactions resulting from the action of microbial enzymes on an organic substrate. They are redox reactions that degrade the substrate and occur in the absence of air (anaerobic conditions), releasing little energy.

The term "fermentation" derives from the Latin word "fervere", meaning "to boil". A liquid undergoing fermentation, such as an alcoholic beverage, exhibits significant gas release and the appearance of a boiling liquid.

Fermentation is a biochemical reaction that converts the chemical energy contained in a carbon source (often glucose) into another form of energy directly usable by the cell, in the absence of oxygen (anaerobic environment). As Louis Pasteur said, "Fermentation is life without air".

From 1857 onwards, he studied acetic, alcoholic, butyric and lactic fermentations. He demonstrated that it was both a chemical and biological process by isolating and cultivating the bacteria or yeasts responsible for these phenomena.

- During the First World War, the increased need for acetone for the manufacture of munitions led to the development of the food processing industries.

#### **3.2 Types of microorganisms**

By feeding on sugars and water, the microorganism replenishes its energy reserves to multiply. It then produces waste products that are beneficial to humans. For example, the bacteria release acid, like the kind you can taste in plain yogurt.

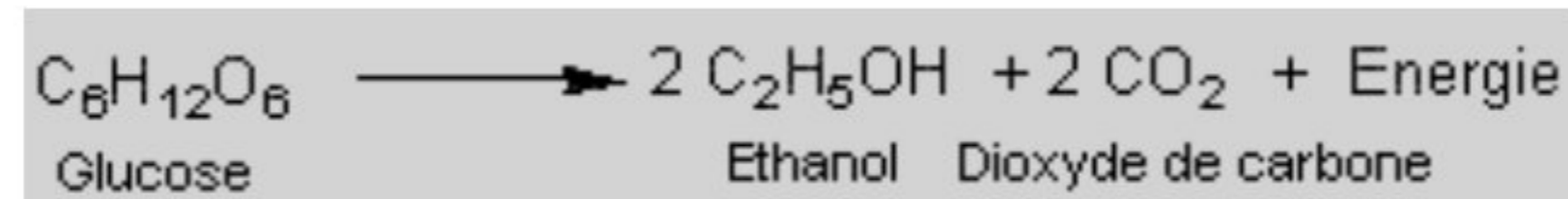
To develop, microorganisms need the right temperature. Above 65°C, most of them die. Below 4°C, they become dormant. Once they have multiplied, they colonize the food and modify its taste, texture, and color, while also preserving it.

### 3.2.1 The main types of fermentation

Fermentation processes are distinguished according to the type of products released by the fermenting microorganism:

#### a. Alcoholic fermentation

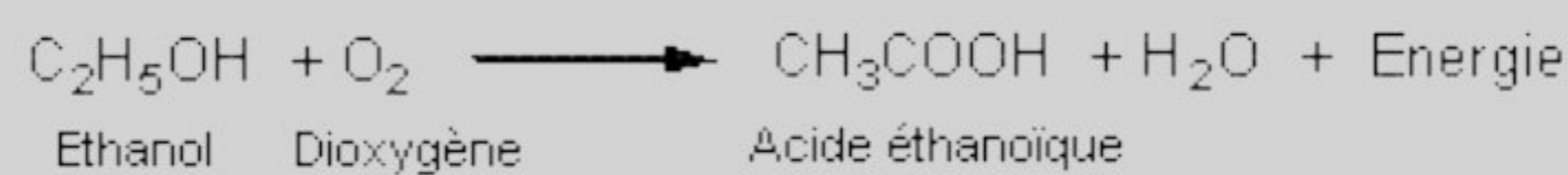
It is a biochemical reaction resulting from the action of yeasts (*Saccharomyces cerevisiae*), which break down sugars into alcohol and carbon dioxide (CO<sub>2</sub>). It is involved in the production of certain alcoholic beverages such as wine, beer, cider and various fermented drinks.



This fermentation process is also used in baking, where the essential factor is the production of CO<sub>2</sub> which makes the dough.

#### b. Acetic fermentation

It is involved in the production of vinegar and is due to bacteria belonging to the genus *Acetobacter*; this bacterium transforms any alcoholic liquid into acetic acid.



#### c. Lactic fermentation

Lactic acid bacteria are a heterogeneous group of microorganisms that produce lactic acid as the main product of their metabolism. They are found in many foods, such as dairy products, meat, vegetables, and grains, as well as in the human and animal intestinal and vaginal flora. They are involved in a large number of spontaneous food fermentations.

It corresponds to the transformation of lactose in milk into lactic acid under the action of lactic acid bacteria.

- *Streptococcus thermophilus*.

- *Lactobacillus delbrueckii* subsp. *bulgaricus*.



It is an essential step in the production of cheeses, yogurts, but also many fermented plant products (silage, olives, pickles, etc.).

It should be noted that the lactic acid fermentations, in addition to their role, play a major stabilizing role (by lowering the pH and reducing antibiosis), but above all a major role in food quality: lactic ferments are sources of growth factors.

### 3.2.2 The main ferments

Ferments are microbial agents that produce the fermentation of a substance. In the agri-food sector, the challenge is therefore to select the beneficial flora and eliminate the undesirable ones.

Microorganisms usable in the food industry must have the following characteristics:

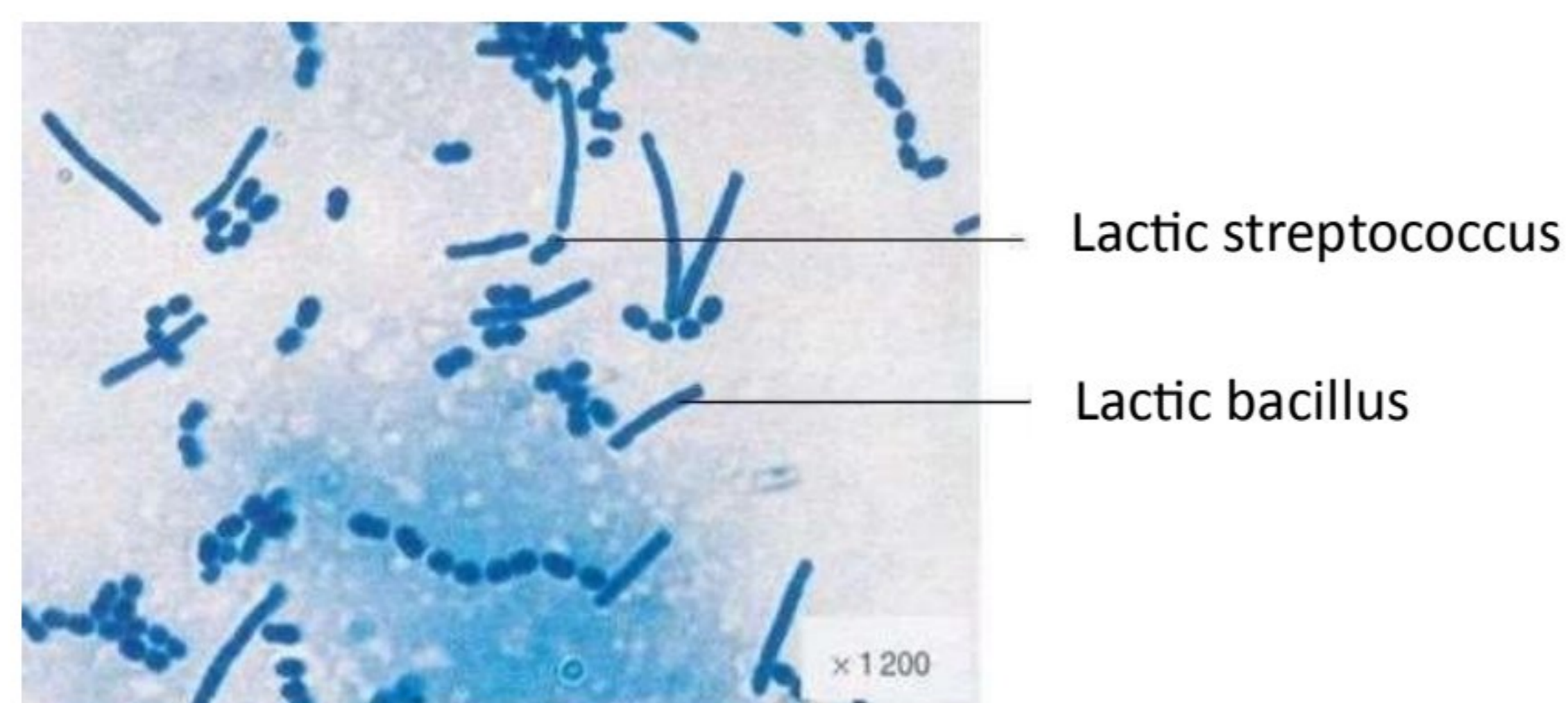
- to present no health risks to human and animal ;
- be easy to use and control.

Next, the criteria for choosing the microorganism must be decided upon and various parameters established: growth conditions, production, specific characteristics, undesired characteristics, sensitivity, and the manufacturer.

### 3.2.3 Bacteria

The bacteria used in the food industry are primarily:

- Lactic acid bacteria, which are found in cheeses, cured meats and sauerkraut (Figure 15)
- acetic bacteria, which are useful in the production of wine products;
- Propionic bacteria, which are used in the production of pressed cheeses.



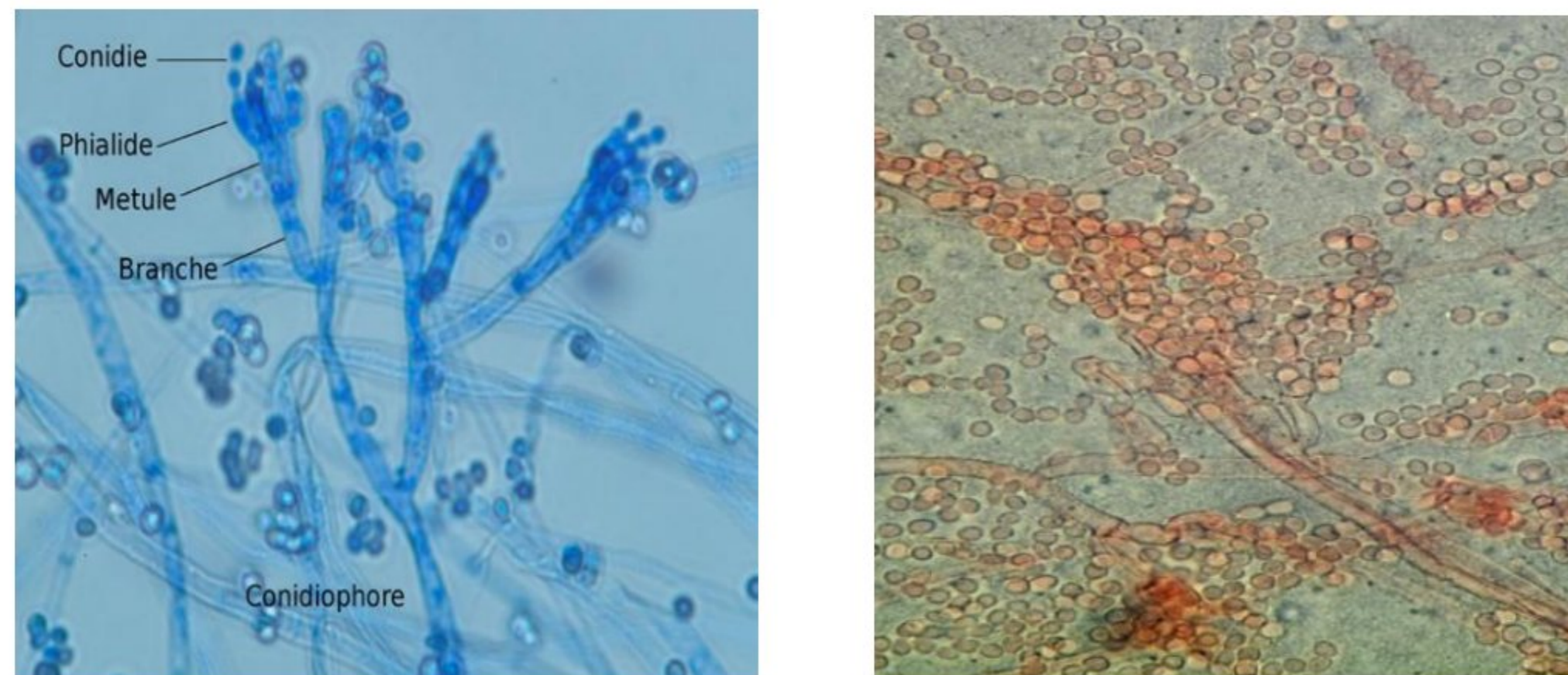
**Figure 15. Microscopic observation of lactic acid bacteria (x1200)**

---

**Noticed :** These bacteria, used in the food industry, sometimes employ fermentation. Their metabolism operates under anaerobic conditions and allows the formation of waste products of interest to the industry.

### 3.2.4 Molds

Molds are capable of producing a wide range of hydrolytic enzymes (lipases and proteases)(Figure 16). They are therefore found in the food industries, particularly in the processes of cheese ripening and the transformation of alcoholic beverages.

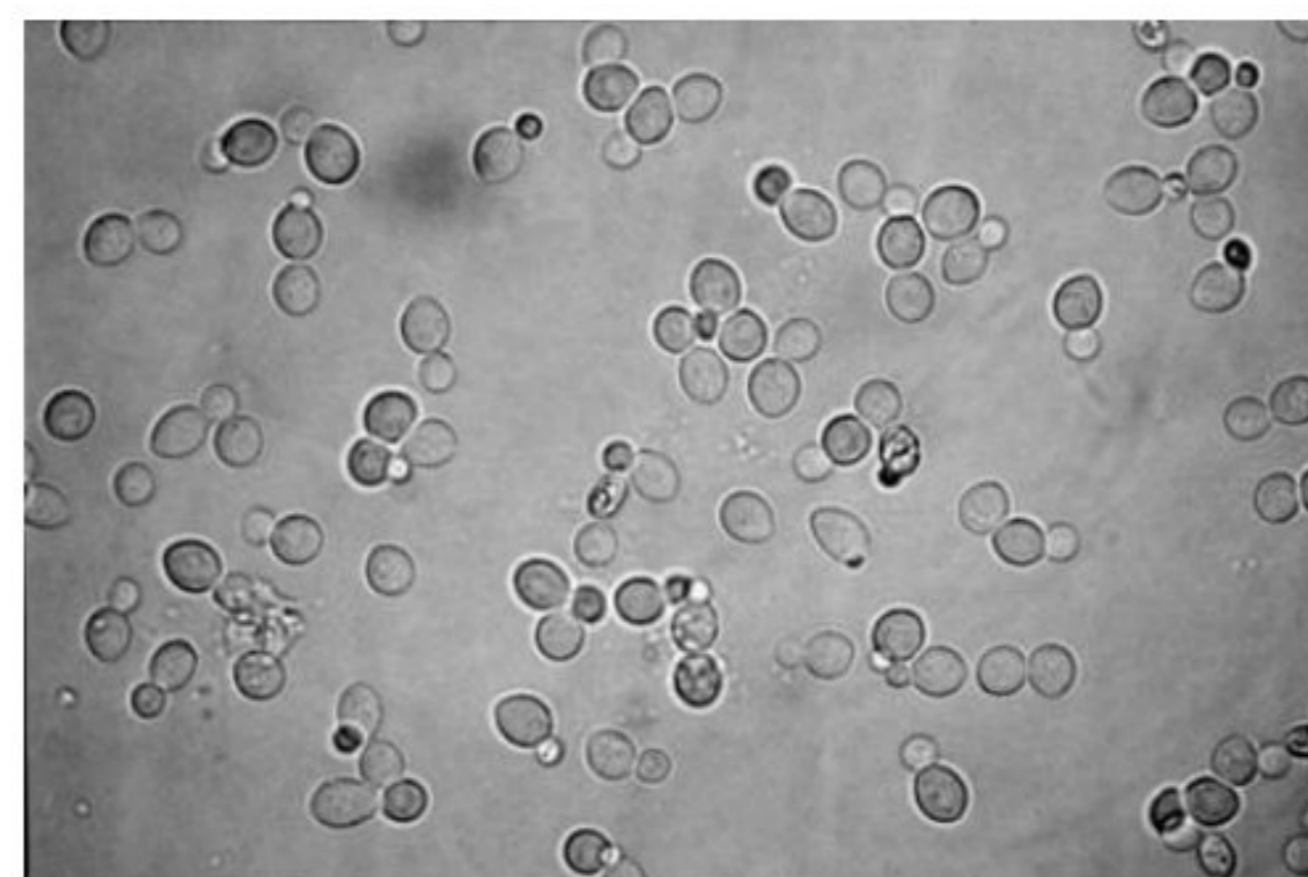


**Figure 16. Microscopic observation of the structure of molds**

---

### 3.2.5 Yeasts

Yeasts can grow in both aerobic and anaerobic conditions (Figure 17). In aerobic conditions, cells carry out classical glycolysis and their growth rate is high. They carry out alcoholic fermentation, which is less energy-efficient, but which leads to the formation of a by-product of interest to humans: ethanol.



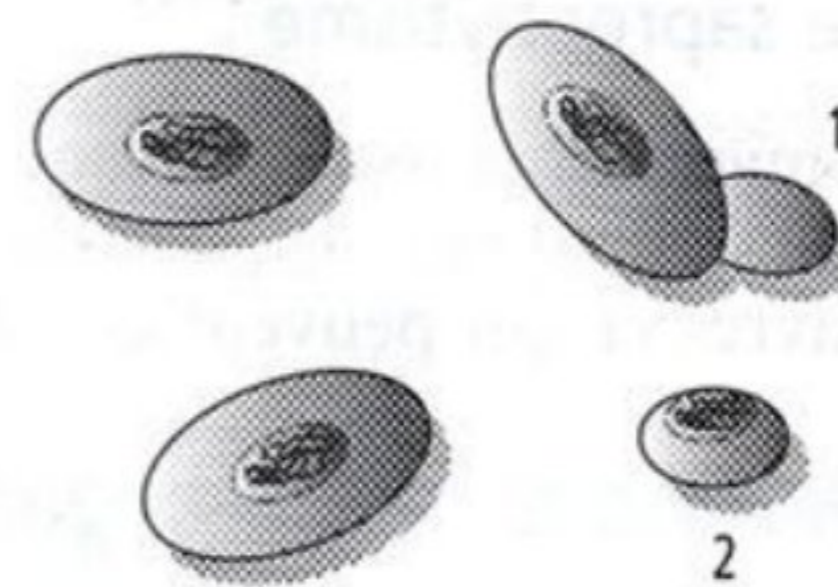
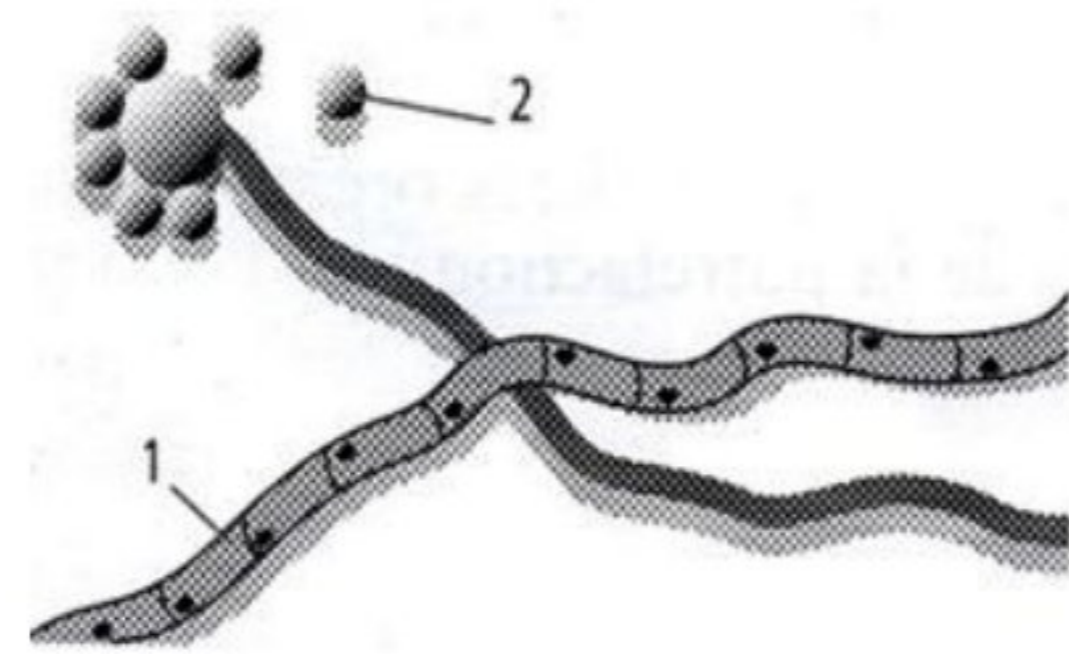
**Figure 17. Microscopic observation of yeast (*Saccharomyces cerevisiae*)**

---

Yeast is a single-celled fungus capable of respiration and fermentation. During fermentation, yeast uses the sugar present in its environment; therefore, it can be cultivated on any glucose-based medium. The most widely used species is *Saccharomyces cerevisiae*, used in winemaking and breadmaking.

**Table 1. Difference in characteristics between yeasts and molds**

Features	Molds	Yeasts
<b>Structure</b>	The filaments are tangled together, each considered as a single and large cell.	Oval cell
<b>Organization</b>	Cell containing a normal nucleus (1), a cell membrane and numerous cytoplasmic organelles	A cell with a nucleus containing chromosomes, a membrane, and cytoplasmic organelles.
<b>Reproduction</b>	The filaments bear spores (2) at their tips; once released, they are dispersed by air movements and will germinate	Buds (1) form on the surface of the yeast, they detach and give rise to a new yeast (2).



### 3.3 The fermenter

A bioreactor, also called a fermenter or propagator, is a device in which microorganisms (yeasts, bacteria, microscopic fungi, algae, animal or plant cells) are multiplied in order to produce biomass or a metabolite.

Unlike simpler systems used to grow microorganisms, such as vials, the bioreactor allows control of culture conditions (temperature, pH, aeration, etc.) and thus provides more reliable information.

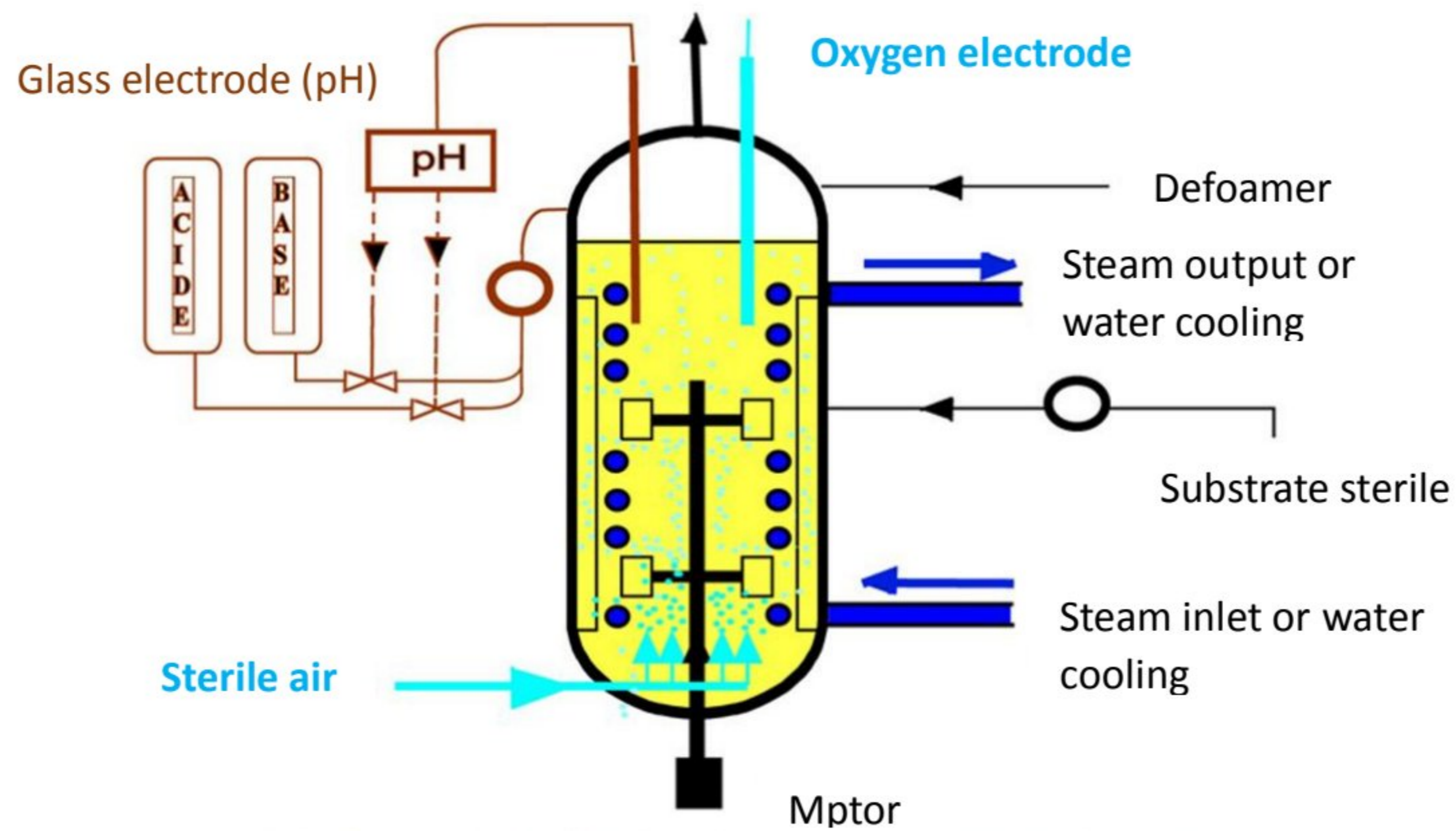
#### 3.3.1 Definition

A fermenter is generally built on the model of a bioreactor, but without an aeration system. In the field of biotechnology, the term "fermenter" is sometimes used interchangeably with "bioreactor." It consists of a glass (for laboratory models) or stainless steel tank or enclosure.

#### 3.3.2 Description

- A stopper allowing control of the passage of air between the internal and external environments;
- A syringe with a catheter for injecting a solution;

- An agitation system comprising one or more turbines, depending on the size;
- Sensors for measuring temperature (thermometer), pH (pH meter) and dissolved oxygen concentration (oximetric probe).
- A computer-controlled system for recording and controlling all operating parameters (Figure 18).



**General scheme of a fermenter**

**Discontinuous**

**Figure 18. General diagram of a batch fermenter**

### 3.3.3 Biomass Production

In microbial engineering, the term "bioreactor" refers to a system for cultivating microbial biomass. Bioreactors are used to manufacture numerous products, including beer, yogurt, food additives, vaccines, antibiotics, antibodies, vitamins, and organic acids. Several types of bioreactors exist.

We can find:

- Laboratory fermenters, whose capacity varies from 0.1 to 15 litres;
- Industrial fermenters, with a capacity of 100 to 100,000 litres.
- Disposable bioreactors: variable volume.

The term biomass refers to the cellular organic material of organisms in culture (animals, plants or microbes).

Microbial biomass is also called Single Cell Protein or single-cell organism protein, also referred as SCP. This microbial biomass can be used to produce proteins, vitamins, antibiotics, vaccines, food additives, food, and bioethanol.

- Biomass is used in the production of these products; this is fermentation.

#### **3.3.4 Production of metabolites**

Various substances or metabolites, usable as food additives, are produced by microbial fermentation.

Amino acids, such as lysine, aspartic acid, threonine or glutamic acid, are used in animal feed.

- Organic acids (lactic, fumaric, acetic acid) are used as acidifying agents for preservation;
- Citric acid is used as an acidifier, antioxidant, emulsifier, and chelating agent.
- Vitamines: ascorbic acid (vitamin C), riboflavin (vitamin B2), cyanocobalamin (vitamin B12), vitamin D, etc.
- Enzymes of microbial origin that can be used during the manufacture or processing of foodstuffs: proteases (to facilitate the tenderizing of meats), lipases (to improve the volume of bread), and amylases (to preserve the freshness of bread and cakes).

## **4. Chapter 3 (Fermenters)**

### **4.1 Role of fermenters**

Biotechnological processes are carried out in bioreactors or fermenters, where molecules are synthesized using strains of bacteria, yeast, and cells. The final product is used in many areas of our daily lives, for example, in the fermentation of yogurt and beer.

Besides applications in the food and beverage sector, it is also used in the field of drug research and production.

- Flow regulators play an important role in these bioreactors.

The rise of biotechnology and the expansion of its field of applications are good reasons to take an interest in this fascinating technology.

The benefit of biotechnology in the agri-food industries is to obtain metabolites.

- useful;

- molecules of industrial interest derived from biological material.

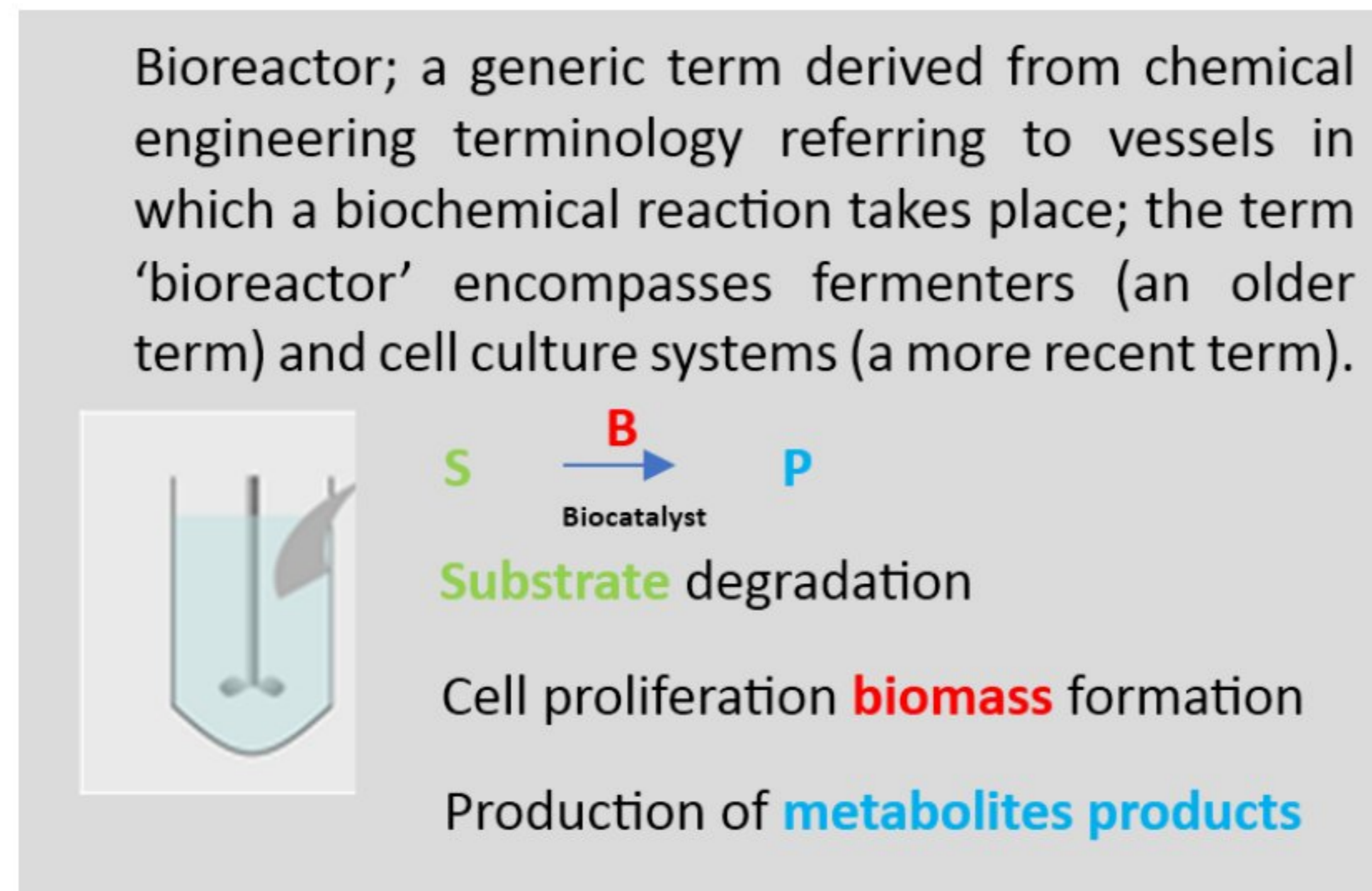
### **4.2 The stages of the fermenters:**

Obtaining these molecules involves two steps:

1. Production of the desired product, called "fermentation", is done using fermentation processes that are constantly being developed to cultivate microorganisms under optimal conditions and allow them to produce the desired products.
2. Recovery of the formed product : the extraction and purification of the product must be carried out by gentle techniques, such as electrophoresis, distillation or chromatography;

### **4.3 The fermenter, the heart of the process**

A bioreactor is a container in which biological processes take place (Figure 19).



**Figure 19. Biomass formation from substrate**

---

Bioreactors are equipped with simple manual control or fully automatic control via a Programmable Logic Controller (PLC). Generally, the bioreactor process is batch.

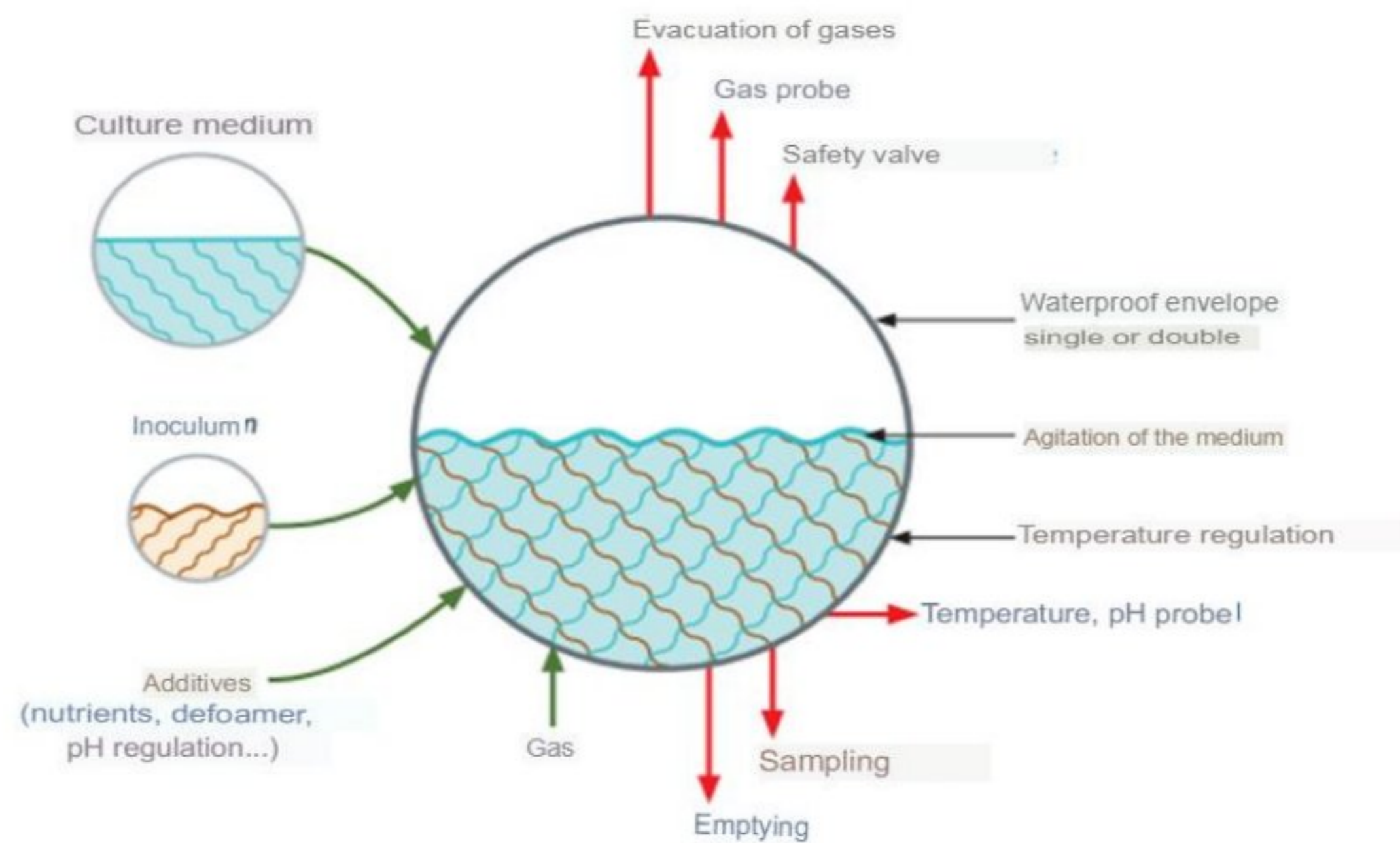
The time between the start and the harvest is called a campaign.

Most bioreactors require a supply of gas and nutrients to allow the growth of bacteria, yeasts or cells, and for the desired biological synthesis to take place.

These additives are usually added continuously over a period ranging from a few days to several weeks (Figure 20).

Flow regulators play an essential role in controlling the process of bioreactors.

A cell culture campaign can last up to three or four weeks before harvest, whereas a bacterial culture campaign often lasts only a few days.



**Figure 20. Input and output elements of a fermenter**

#### 4.4 Description of a fermenter

- Carrying out the process stably during this period, presents a challenge, and therefore it is very important to accurately dose the gases and nutrients.
- Flow rate variations have significant consequences, both for bacteria and for cell cultures.
- The dosage of all additives is carried out under sterile conditions to avoid any contamination by undesirable bacteria that could compete with the microbial or cell culture.

In short, reliability but above all reproducibility are key elements in bioreactor processes, particularly concerning flow rate regulation.

##### \*Bioreactor aeration using mass flow regulators

The gases that are commonly used to aerate bioreactors are: air, oxygen ( $O_2$ ), nitrogen ( $N_2$ ) and carbon dioxide ( $CO_2$ ). Where,

Nitrogen ( $N_2$ ) is used to calibrate the oxygen sensor ( $pO_2$ ) and to reduce the  $O_2$  content in the bioreactor at the beginning of the process. The larger the number of bacteria or cells, the greater the need for  $O_2$ .

$CO_2$  is used to regulate the acidity (pH) in the liquid phase.

A bioreactor is generally regulated by checking the partial pressure of oxygen  $pO_2$  and the pH in the suspension. The absorption of oxygen and all other substances by the cells takes place in the liquid phase.

Oxygen must therefore be present in the liquid.

To do this, oxygen (in the form of a component of air, for example) should be added to the smallest possible bubbles.

Stirring the liquid helps to distribute and diffuse the added oxygen.

#### **4.5 The history of bioreactors**

Research and the first production of microbiologically generated substances for medicinal purposes began during World War II, when the benefits of penicillin for treating wounded soldiers were discovered.

It was then observed that the use of bacteria in microbiological processes offered an advantage over more conventional chemical synthesis. Indeed, in chemical syntheses, numerous residual compounds are generated, some even in proportions far exceeding the desired substance itself.

In contrast, biological syntheses yield much higher amounts of the target substance. Furthermore, this type of synthesis often offers simpler separation methods. Moreover, bacteria, like human and animal cells, synthesize specific substances that are inaccessible, or very difficult to access, through conventional chemical synthesis.

Over the past 20 years, powerful bacterial strain isolation processes and other genetic engineering methods have enabled us to produce, isolate, and multiply strains, that synthesize target substances specifically, selectively, and efficiently. In most cases, these syntheses are carried out in bioreactors.

#### **4.6 Applications of the bioreactor**

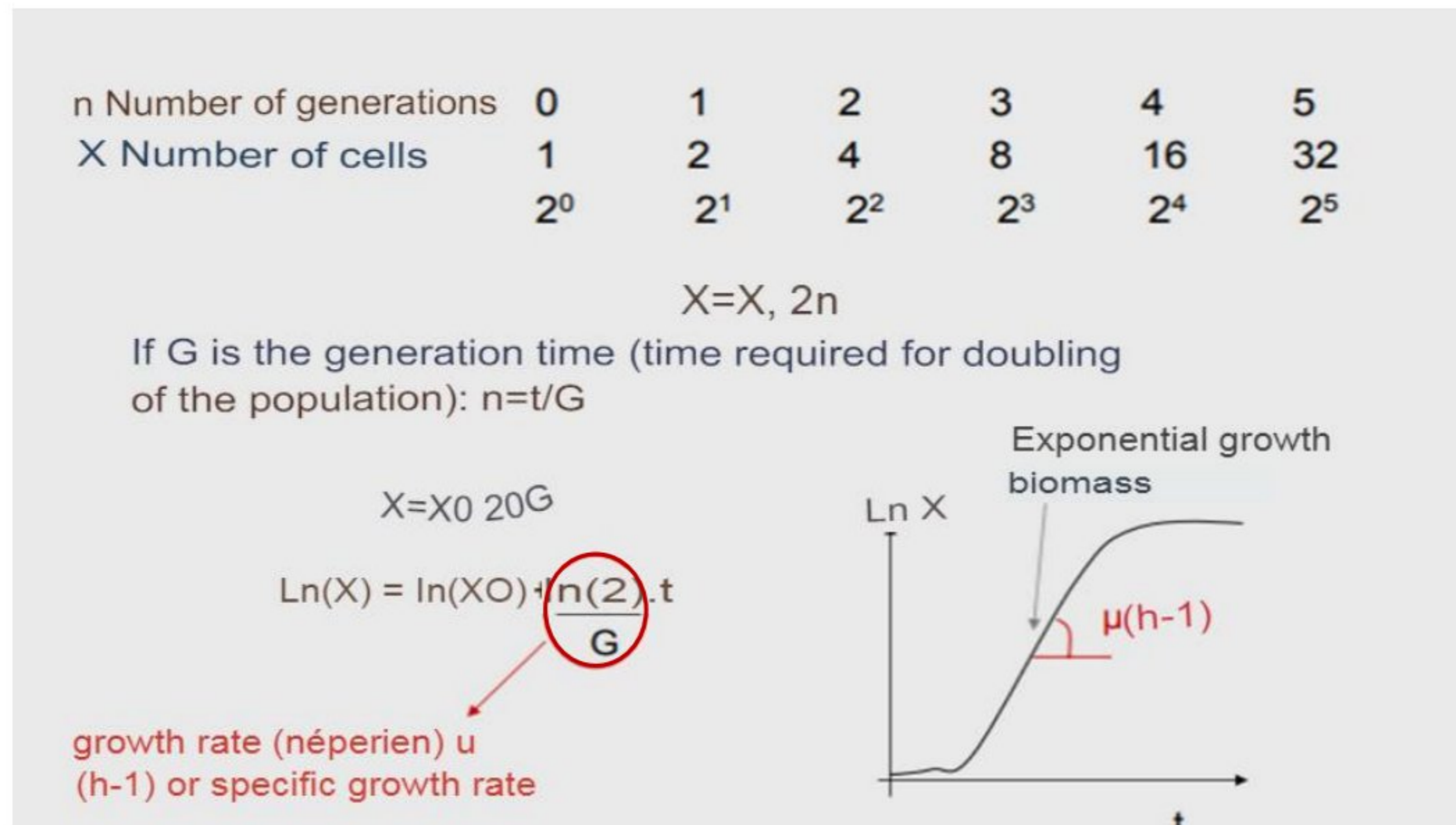
Bioreactors come in various sizes and shapes, making them suitable for a wide range of applications. They range from the smallest reactors with a capacity of a few milliliters to large bioreactors with capacities up to 100 m<sup>3</sup>.

Typically, the oxygen flow rate is 0.1 to 0.15 times the working volume per minute for cell cultures and up to 2 times for bacterial cultures. Bioreactors, then called fermenters, are used in food and beverage production for fermentation purposes, whether to add vitamins, colorings, flavorings, alcohol, or antioxidants.

For example, yogurt is a product made from fermented milk in fermenters. Yogurt cultures are lactic acid bacteria. Or beer... in the beer brewing process, yeast cells are used to convert sugars into alcohol.

And what about cheese? Originally, cheese was made from milk by adding natural rennet, an enzyme derived from a plant or animal. Nowadays, rennet for cheesemaking is produced by yeast cells cultivated in a fermenter. All of these are examples of fermenter applications.

Microorganisms have long been used in food production, but why has biotechnology gained so much popularity since the second half of the 20th century (Figure 21).



**Figure 21. Example of a biomass growth curve**

## 4.7 Different fermentation systems

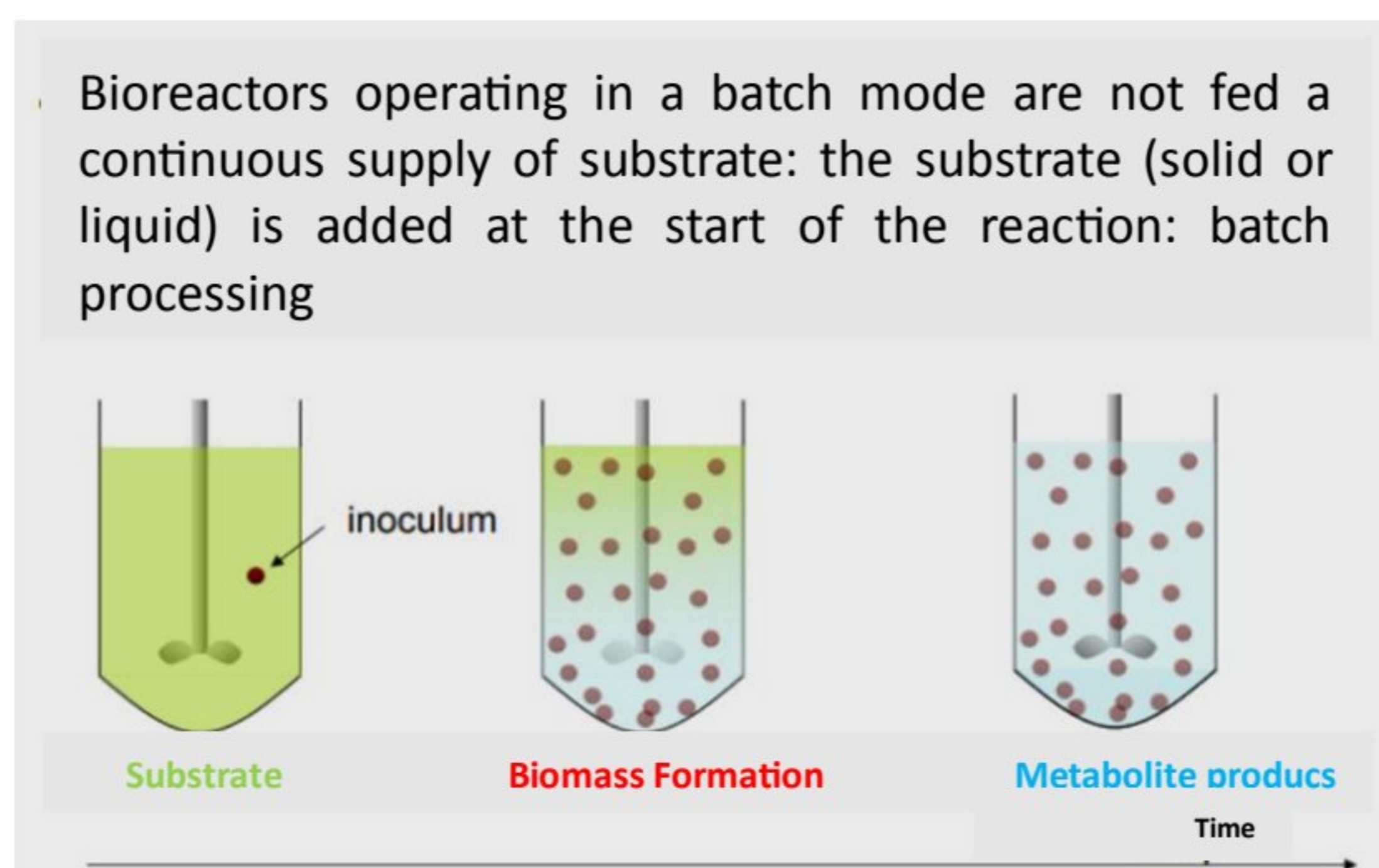
There are 3 main fermentation systems.

### 4.7.1 Batch or discontinuous (closed) fermentation

The first fermentation system, called batch or discontinuous fermentation, is a closed system. At the beginning of fermentation, the sterile nutrient solution is inoculated with microorganisms (bacteria, yeasts).

Incubation takes place under the controlled conditions like agitation, temperature, partial pressure of oxygen and pH.

During incubation, the quantity of microorganisms in the fermenter, as well as the concentration of biomass, substrate, and product, may vary constantly, due to microbial metabolism (Figure 22).

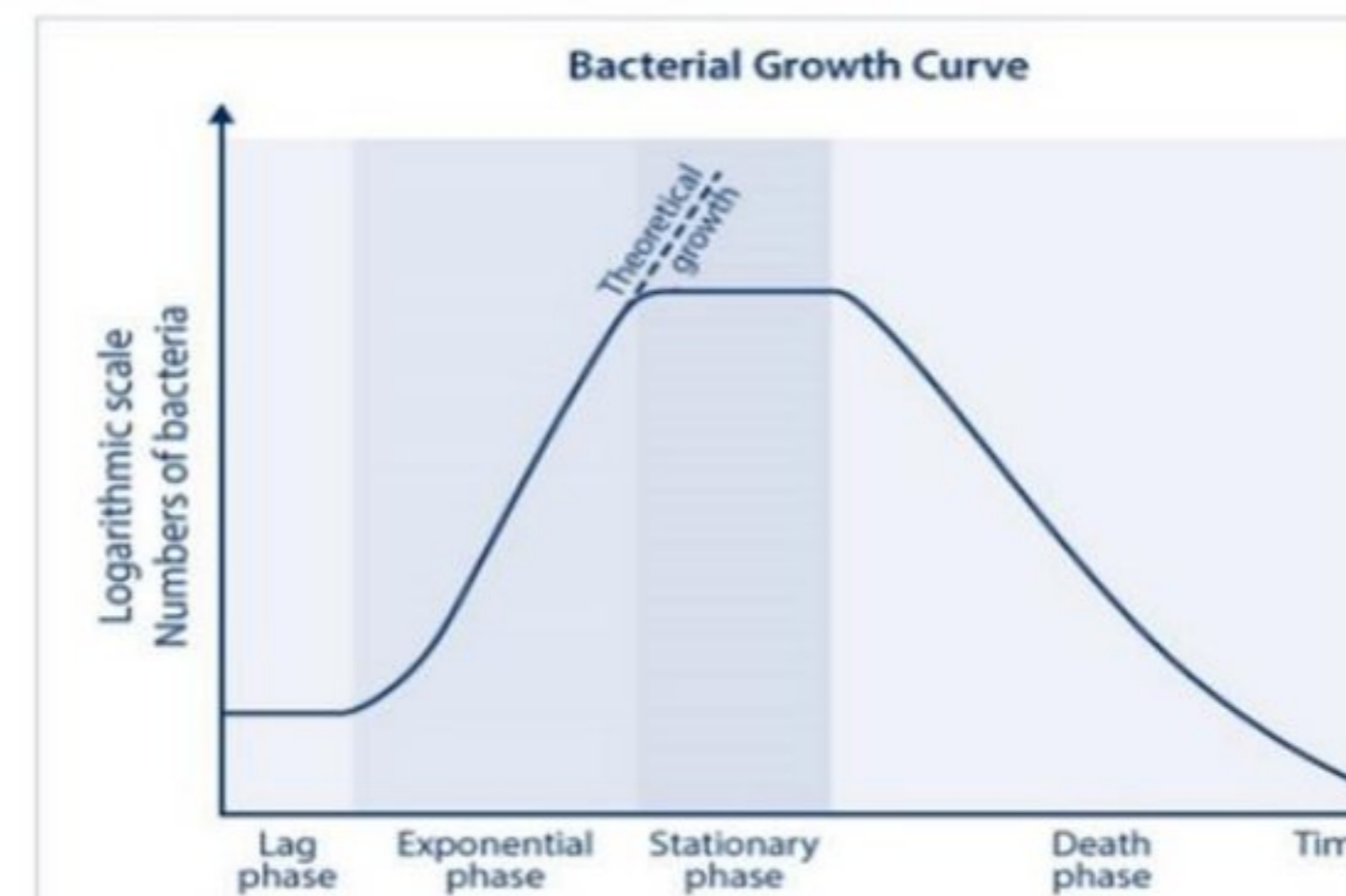


## Figure 22. Principle of a batch fermenter

---

Four phases of growth can be observed :(Figure 23)

- A latency phase
- An exponential growth phase
- A stationary phase
- A phase of mortality



## Figure 23. Logarithmic microbial growth phase

---

### 4.7.2 Fermentation Fed Batch or fed

The second fermentation system, called "fed bath fermentation," involves providing the substrate, as it is consumed by the microorganisms (Figure 24).

This system is used to produce penicillin. Penicillin undergoes catabolic repression in the presence of a high concentration of a carbon substrate (glucose). The substrate is added gradually as it is consumed to prevent its accumulation in the reaction.

- The bioreactor operating in semi-continuous (or in batch fed or fed batch) are partially supplied: the substrate is introduced throughout the reaction but without that there is racking of the medium -> the volume increases
  - Advantages: allows you to increase the volume as the growth of the biomass
  - In practice: Stopping the power supply when the volume reaches a certain value

The diagram shows a stirred tank reactor with a central agitator. A substrate inlet is shown at the top left. The reactor contains a liquid medium with a central agitator and a substrate inlet. The volume of the medium is shown increasing as the reaction progresses.

## Figure 24. Principle of a semi-continuous fermenter

---

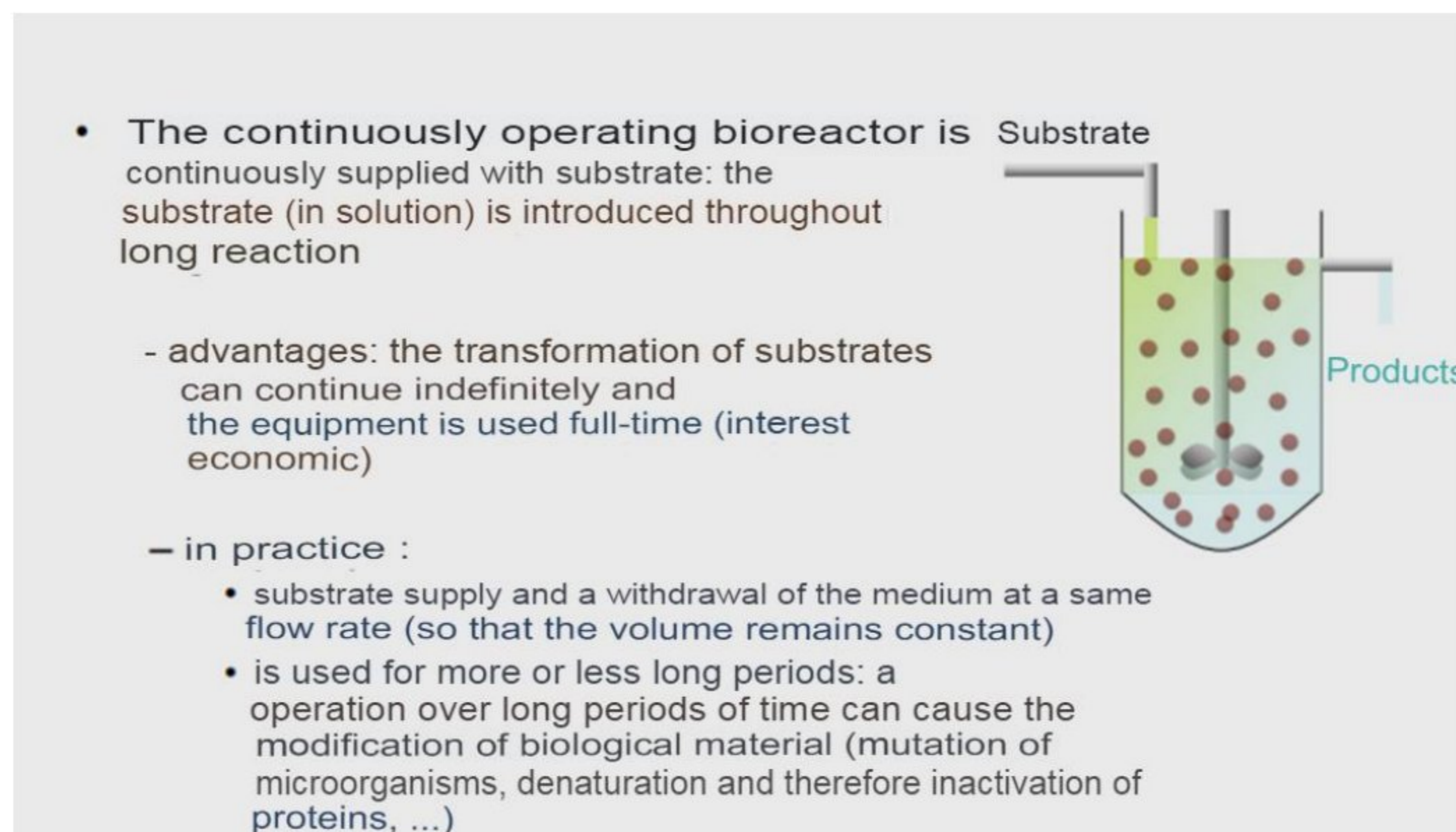
### 4.7.3 Continuous fermentation or open system

The third fermentation system is called continuous fermentation or the open system (Figure 25).

The nutrient solution is continuously fed into the reactor, but an equivalent amount of fermented solution is withdrawn. The volume is therefore constant.

There are two main types of continuous fermenters:

- The plug flow reactor
- The Infinitely Mixed Reactor



**Figure 25. Principle of a continuous fermenter**

These two types of fermenters differ in the way the nutrient solution flows.

It is characterized by a very high length-to-width ratio. It is a cylindrical reactor 10 to 15 meters long. The nutrient solution enters at one end of the reactor, while the cellular biomass and the collected product are discharged at the other end.

In this type of reactor, turbulence is zero. An element entering the reactor progresses without mixing with the molecule preceding or following it.

This generates concentration gradients inside the reactor. The further one is from the reactor inlet, the lower the substrate concentration and the higher the product concentration.

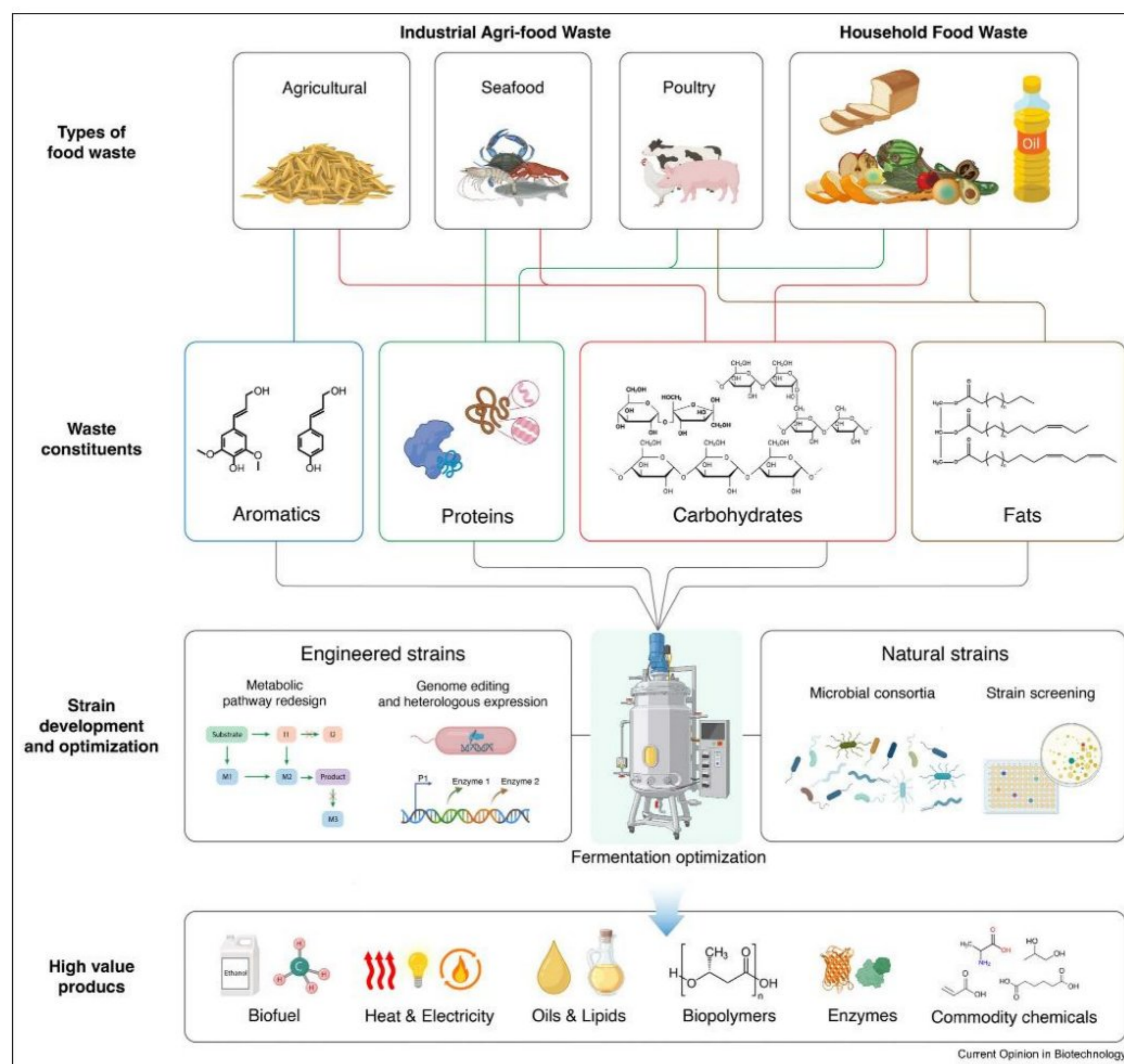
The disadvantage of this type of reactor is the difficulty in regulating the pH.

Indeed, the pH is different at every point in the reactor.

The homogeneity of the reactor contents is perfect.

Any element entering the reactor is homogenized with its contents. The concentration of a given compound is the same at every point in the reactor. The concentration of a given compound in the reactor effluent is identical to that of the same compound inside the reactor.

The growing problem of food waste and its environmental impact could be solved by considering it as a raw material for producing high-value compounds. The diversity of food waste offers a wide range of substrates, each suited to a specific microbial platform for bioconversion into valuable products. From bacteria and yeasts to microalgae, each microorganism has demonstrated its ability to transform food waste into valuable compounds, such as biofuels or chemicals, and this ability can be enhanced through metabolic engineering. By optimizing substrate types based on microbial capabilities, it is possible to develop customized bioprocesses to maximize product yield, process efficiency, and economic viability.



**Figure 26. Role of the biofermenter in waste valorization**

## **5. Conclusion**

Advances in biotechnological tools for identification, processing, and extraction have increased the number of food ingredients derived from nature that possess potential functional properties. Biotechnology enables the customized production of value-added biological compounds by various organisms under specific and controlled growth conditions, using well-designed bioreactors. While significant progress has been made in recent years, further multidisciplinary research is still needed. The real challenge lies in scaling up the process from the discovery of new and transgenic strains to their commercial application for producing functional food ingredients.

## 6. Revision

### 1<sup>st</sup> model of revision

#### Fill in the blanks

Biotechnology is a multidisciplinary science involving:

- 1- ..... ; 3- .....  
2- ..... ; 4- .....

Ferments are microbial agents that cause the fermentation of a substance. The challenge in the food industry is therefore to select the ..... flora and eliminate the .....flora.

There are three types of fermentation; please list them and give an example of the microorganisms responsible for each:

- Fermentation ..... : .....
- Fermentation ..... : .....
- Fermentation ..... : .....

The evolution of biotechnology:

- 7000 BC - ..... discovered fermentation through the production of beer.
- 6000 BC - Yoghurt and cheese are made using ..... that produce lactic acid.
- 4000 BC - The Egyptians bake ..... with yeast.
- 250 BC - The Greeks practice crop rotation to ..... the soil.

What are the main stages in the development of biotechnology?

.....  
.....  
.....  
.....  
.....  
.....  
.....

Define transgenesis and give two examples of its application in the agri-food industry

.....  
.....  
.....  
.....

Example of a commonly used genetically modified product: .....

What are the main categories of biotechnology?

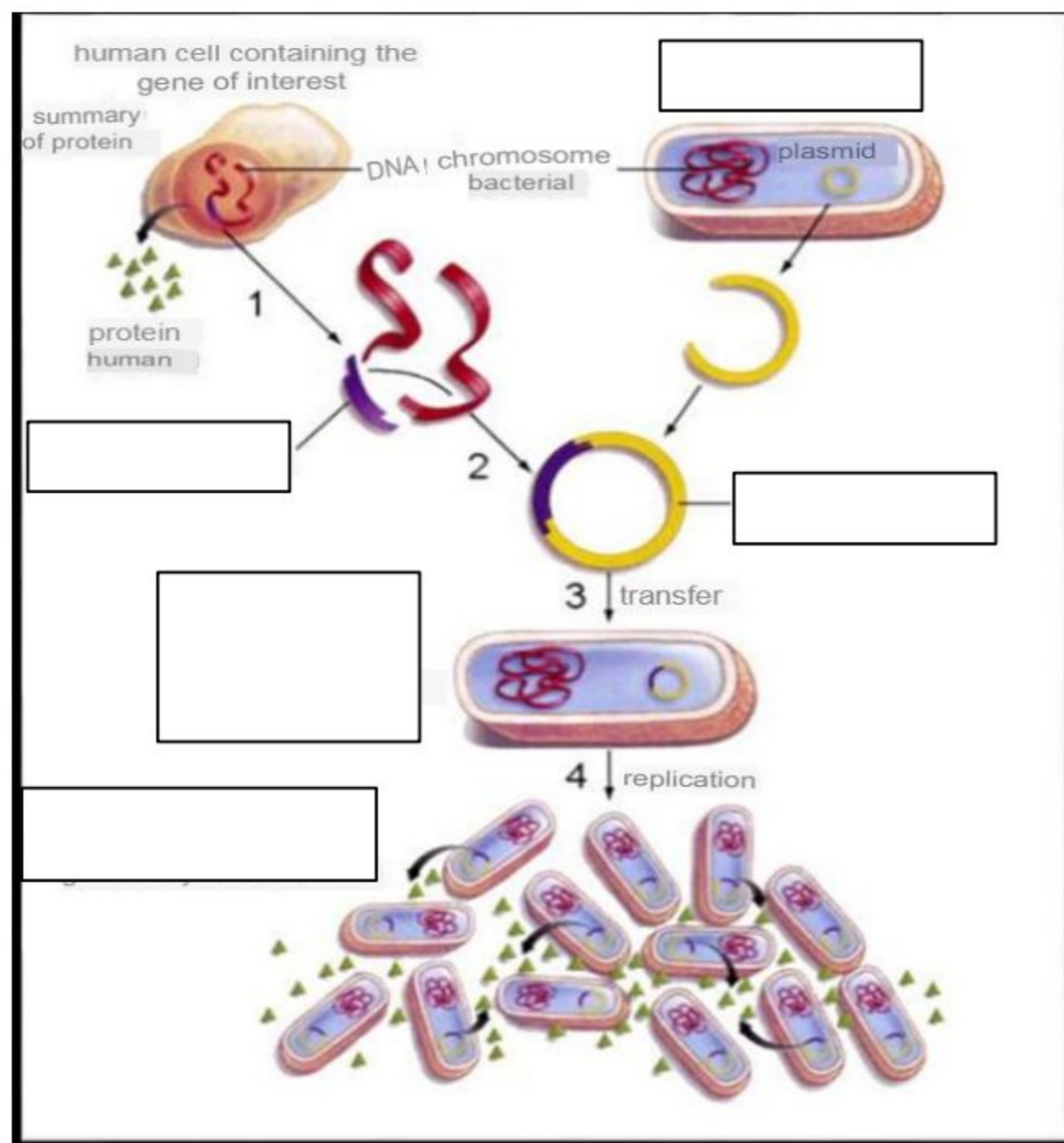
.....

.....

.....

.....

Add captions to the diagram

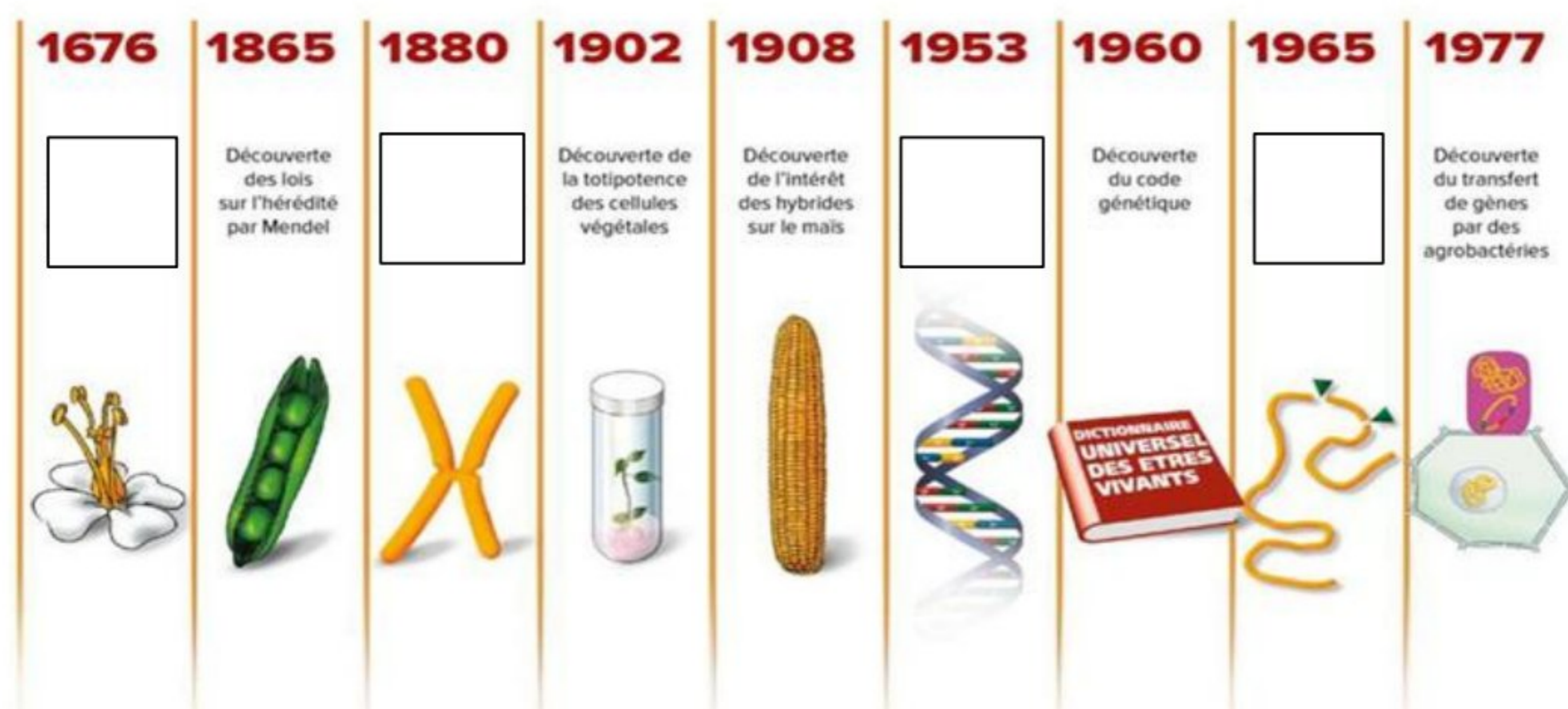


## 2<sup>nd</sup> Model of revision

### Fill in the blanks

Unlike microorganisms, enzymes can be handled in much the same way as .....  
A chemical molecule; they do not cause as many side reactions and do not .....,  
which avoids biomass-related problems.

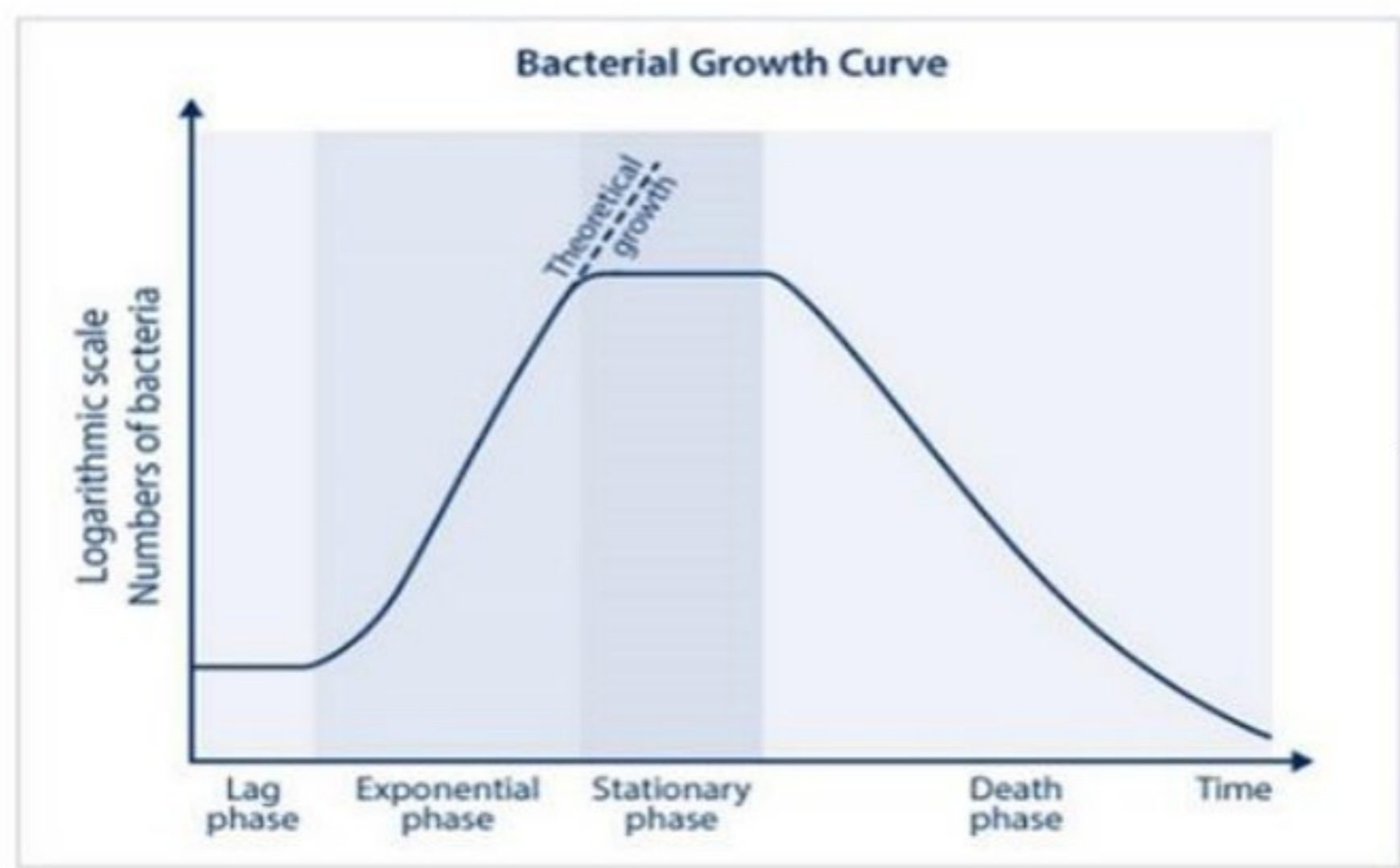
### Add captions to the following figure



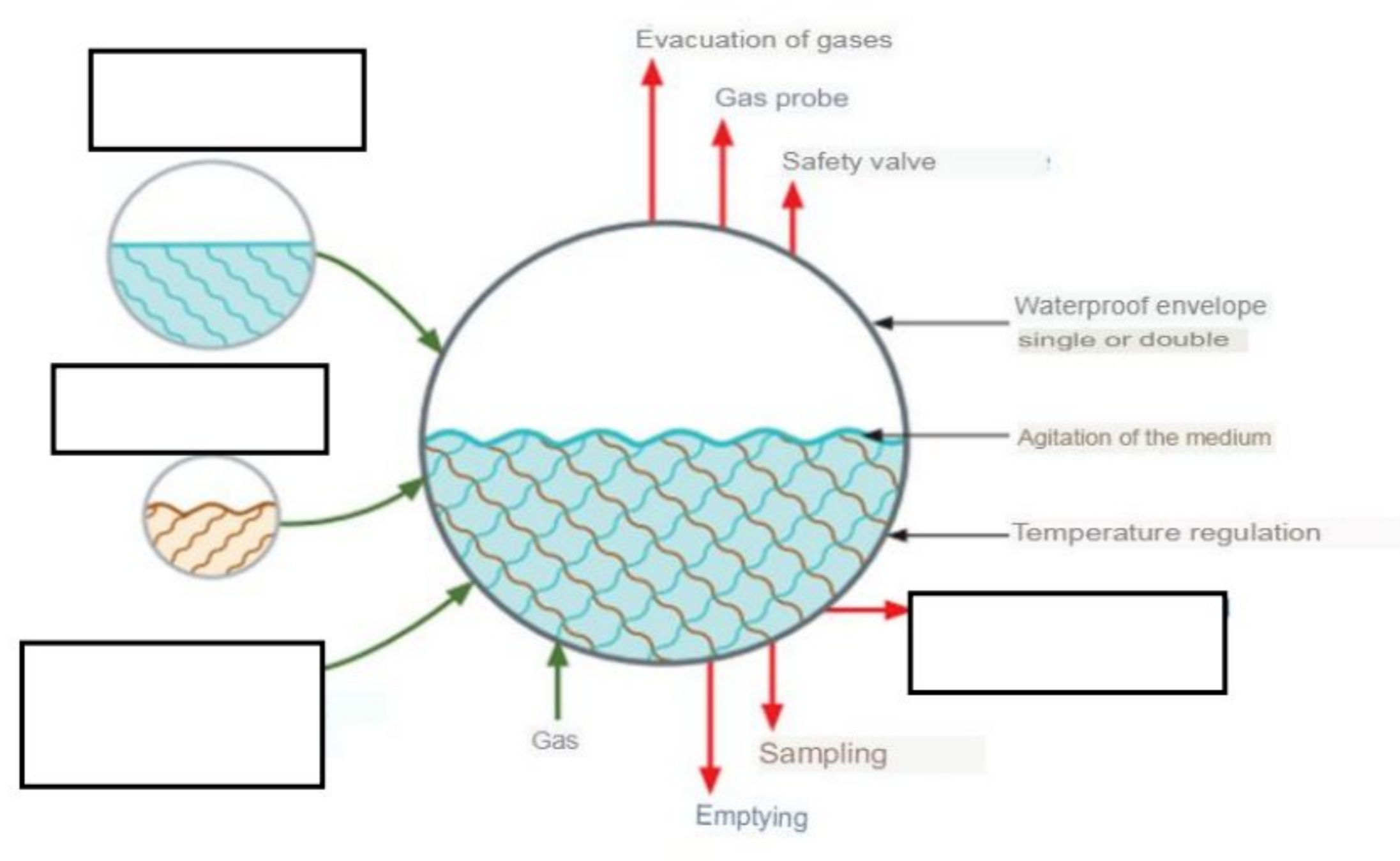
### Define a fermenter and describe its various systems

.....  
.....  
.....  
.....  
.....  
.....  
.....  
.....  
.....  
.....

Add captions to the diagram



- 1- Phase .....
- 2- Phase .....
- 3- Phase .....
- 4- Phase .....



## 7. Bibliography

Chai, WY, Teo, KTK, Tan, MK, & Tham, HJ (2022). Fermentation process control and optimization. *Chemical Engineering & Technology*, 45(10), 1731-1747. <https://doi.org/10.1002/ceat.202200029>

Davies, K.M., & Deroules, S.C. (2014). Prospects for the use of plant cell cultures in food biotechnology. *Current opinion in biotechnology*, 26, 133-140. <https://doi.org/10.1016/j.copbio.2013.12.010>

Dortu, C., & Thonart, P. (2009). Bacteriocins of lactic acid bacteria: characteristics and benefits for the biopreservation of food products. *Biotechnology, Agronomy, Society and Environment*, 13 (1), 143-154. <https://hdl.handle.net/2268/17346>

Dubois, L. (1996). Food, a future miracle of biotechnology?. *Sociology and societies*, 28(2), 45-57.

Fleurence, J. (2023). *Blue biotechnologies: from genetic engineering to enzymatic or fermentative engineering*. ISTE Group.

Freitas, AC, Rodrigues, D., Rocha-Santos, TA, Gomes, AM, & Duarte, AC (2012). Marine biotechnology advances towards applications in new functional foods. *Biotechnology advances*, 30(6), 1506-1515. <https://doi.org/10.1016/j.biotechadv.2012.03.006>

Iñiguez-Moreno, M., González-Meza, GM, Araújo, RG, Flores-Contreras, EA, & de la Rosa, O. (2025). Microalgae biomass as a sustainable solution for food security: Advances in biotechnology and their role in achieving Sustainable Development Goals. *Bioresource Technology Reports*, 31, 102183. <https://doi.org/10.1016/j.biteb.2025.102183>

Lafontaine, C. (2024). Living materials, objects like any other? *Socio-anthropology*, (49), 9-16.

Li, S., Li, P., Feng, F., & Luo, LX (2015). Microbial diversity and their roles in the vinegar fermentation process. *Applied microbiology and biotechnology*, 99(12), 4997-5024.

Mazguene, S. (2023). Lactic acid bacteria metabolism: mini-review. *Current Nutrition & Food Science*, 19(2), 94-104. <https://doi.org/10.2174/1573401318666220527124256>

Mirsalami, S.M., & Mirsalami, M. (2025). Advances in genetically engineered microorganisms: Transforming food production through precision fermentation and synthetic biology. *Future Foods*, 11, 100601. <https://doi.org/10.1016/j.fufo.2025.100601>

Osman, A. (Ed.). (2018). *Progress in Food Biotechnology (Vol. 4)*. Bentham Science Publishers.

Proux, V. (2016). *Biotechnologies. The promises of life*. FYP editions.

Quintin, J. (2001). The threat of biotechnologies: a choice between life and existence. *Vertigo. The international journal in environmental sciences*, (2-1).

Renard, CM (2022). Food transformation: how processes and products have developed. *Cahiers de Nutrition et de Diététique*, 57(3), 169-181. <https://doi.org/10.1016/j.cnd.2021.12.002>

Schmid, RD (2005). *Pocket Atlas of Biotechnology and Genetic Engineering*. Flammarion.

Sharma, T.R., Deshmukh, R., & Sonah, H. (Eds.). (2020). *Advances in agri-food biotechnology*. Singapore: Springer. (eBook) <https://doi.org/10.1007/978-981-15-2874-3>

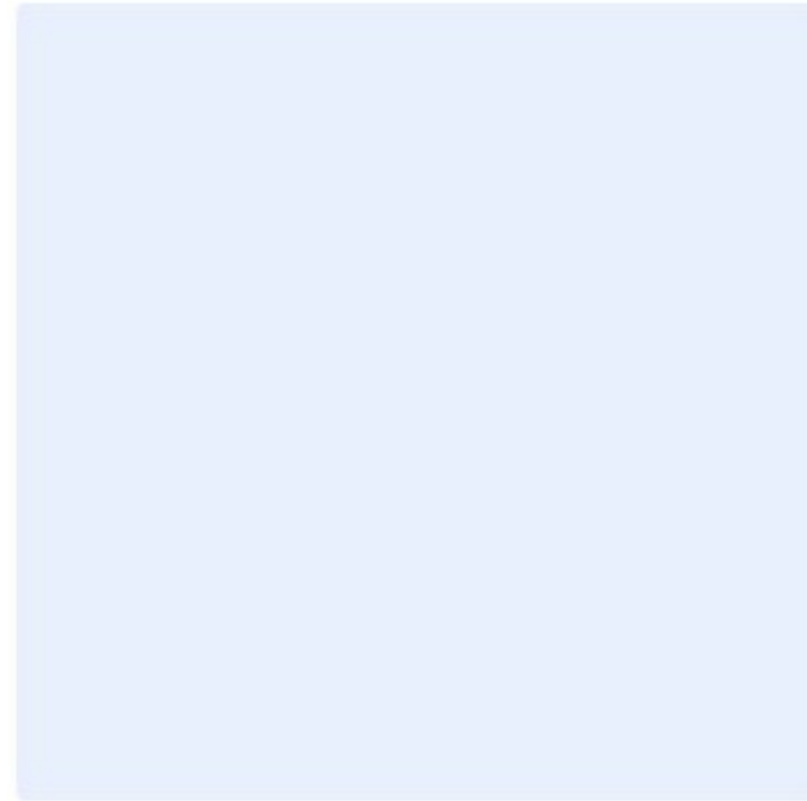
Soon, WL, Foo, JL, & Chang, MW (2025). Microbial food waste valorization: advances, challenges, and perspectives. *Current Opinion in Biotechnology*, 94, 103323. <https://doi.org/10.1016/j.copbio.2025.103323>

Stiles, M.E., & Holzapfel, W.H. (1997). Lactic acid bacteria of foods and their current taxonomy. *International journal of food microbiology*, 36(1), 1-29.

Terestchenko, M. (2010). Accepting the given, mastering life? Brief reflections on the spirit of biotechnology. *La pensée de midi*, 30(1), 90-98.

Zeng, S., Lin, S., Jiang, R., Wei, J., & Wang, Y. (2025). Biotechnology advances in natural food dye acylated anthocyanin production. *Food Frontiers*, 6(2), 698-715. <https://doi.org/10.1002/fft2.527>

## Biography



The author, Dr. Fatima Zahra Ghanemi, is a quality control and analysis engineer with a doctorate in nutrition. She is the former head of the Master's program in Food Science, Agri-food, and Quality Control, and a team leader at the Laprona research laboratory. She directs several Master's thesis projects in food biotechnology, focusing on topics such as yogurt, naturally leavened bread, lacto-fermented vegetables, kombucha, and milk kefir. She acquired cell culture techniques for colon cancer cells during internships at the University of Burgundy. This book is intended for students as well as anyone wishing to learn about food biotechnology, providing a clear and accessible introduction to its fundamental principles.