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Intended for Master's 2nd Year Plant Biotechnology students

Natural Substances and Bio-industries

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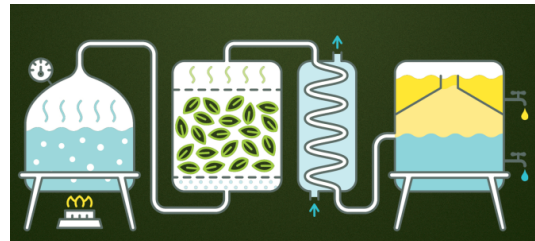
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Natural substances and Bioindustries

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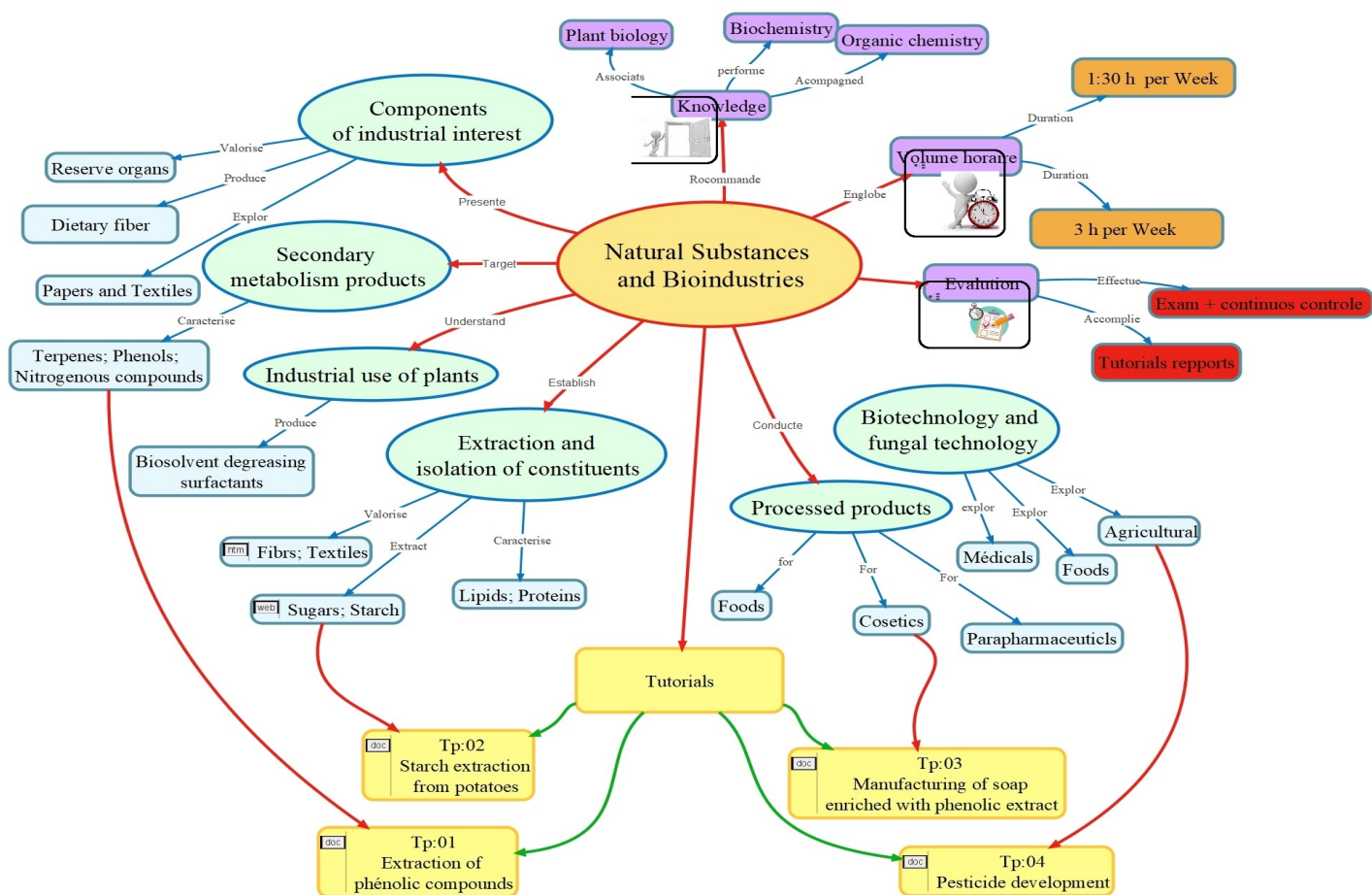
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Learning objectives

At the end of the Natural Substances and Bio-industries module, you will be able to

- Identify organs and tissues of industrial interest.
- Differentiate between secondary metabolites and primary metabolites.
- Link biotechnological applications to species of economic interest.



Concept map of the Natural Substances and Bio-industries module

Development of Economically Relevant Components and Organs

I

By the end of this chapter, "Development of Components and Structures of Economic Interest", you will be able to identify and assess the commercial potential of plants.

1. Introduction

Since the earliest times, humans have relied on plants both for food and for medicinal purposes. Today, 60 to 70% of pharmaceutical products are derived from natural substances, such as aspirin, originally obtained from willow bark, and antibiotics, produced by lower fungi.

From a nutritional perspective, plants—or parts of plants—constitute the majority of human food. For example, flour from common wheat (*Triticum aestivum*) represents a staple ingredient. Plants also play a critical role in dietary fiber production, with cereals serving as an important source.

The wood industry similarly has its roots in agricultural practices, spanning from tree planting to forest exploitation. In paper production, fibers are extracted from the cellulosic components of wood to create usable material.

These examples provide a general overview of the economic and industrial importance of plant-derived natural substances, whether for direct use in food or following technological processing for industrial applications.

2. Storage organs and molecules in plants

Reminder

Chlorophyll-containing cells are the primary sites of photosynthesis and are therefore responsible for the synthesis of all major plant constituents. Through the absorption of light energy by chlorophyll, atmospheric carbon dioxide is converted into organic molecules, mainly carbohydrates, which serve as structural components and reserve substances in plants. These photosynthetically derived compounds are subsequently transformed and stored in the form of reserve molecules such as starch, oils, and, to a lesser extent, proteins, ensuring plant growth, development, and survival.

2.1. Major Storage Compounds in Plants

2.1.1. Carbohydrate reserves

Saccharose

This sugar is widely distributed in many angiosperms, where it often represents the preferred form of carbohydrate transport via the phloem sap. It can also be stored in large amounts in the vacuole of certain tissues, as observed in sugar beet (*Beta vulgaris*). see chemical structure of sucrose Figure 1.1

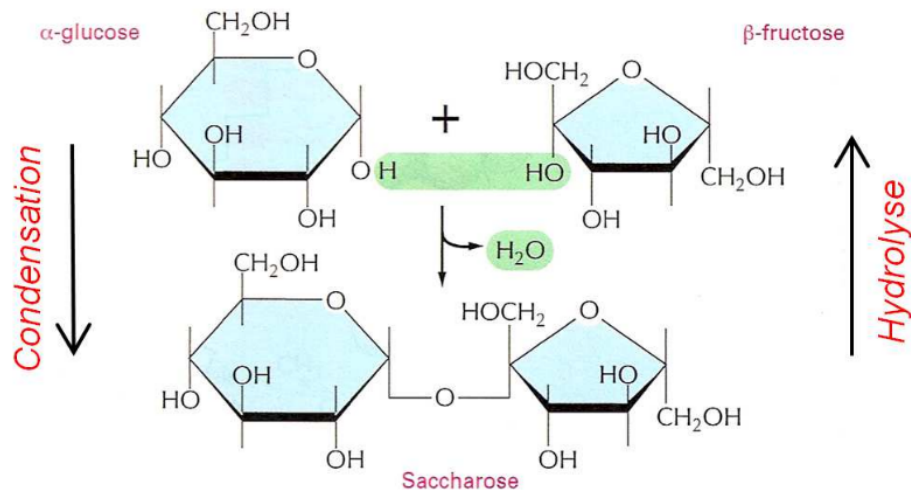


Figure 1.1 chemical structure of Saccharose

Starch:

Starch consists of two types of molecules present in variable proportions depending on the species or the tissue.

- Amylose (Figure 1.2): linear chains of α -D-glucose units linked by $\alpha(1\rightarrow4)$ glycosidic bonds, containing approximately 200 to 3,000 glucose residues.
- Amylopectin (Figure 1.2): branched chains of α -D-glucose units linked by $\alpha(1\rightarrow4)$ glycosidic bonds, with branching points formed by $\alpha(1\rightarrow6)$ linkages every 12 to 30 glucose residues, reaching up to 100,000 residues.

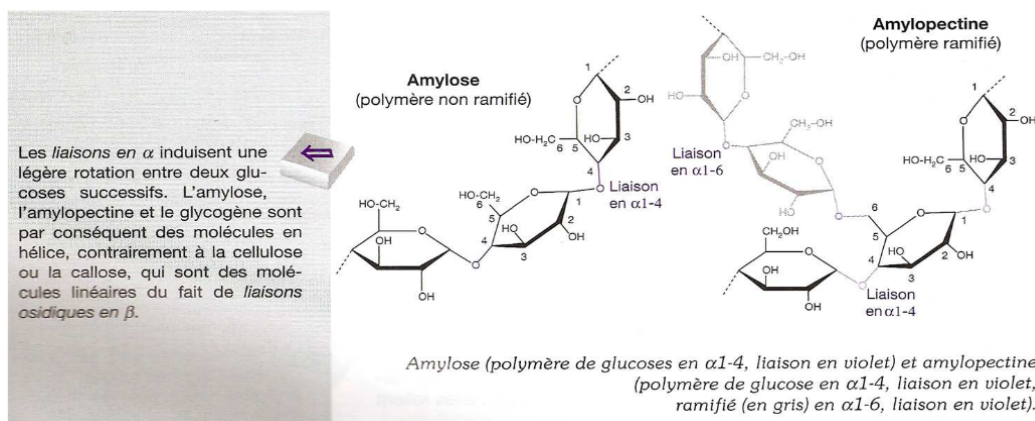


Figure 1.2 Chemical structure and composition of starch. According to DENGEUD et al. (2013) and CAMPBELL & REECE (2004).

In angiosperms, starch occurs in chloroplasts in the form of granules within the stroma. However, it is predominantly stored in large amounts in the amyloplasts of sink organs, where it accumulates as a paracrystalline structure composed of concentric layers, known as starch grains

2.1.2. Lipid reserves

Fundamental

Lipid reserves are mainly composed of triglycerides, also known as triacylglycerols, which are triesters formed from fatty acids and glycerol. see Figure 1.3

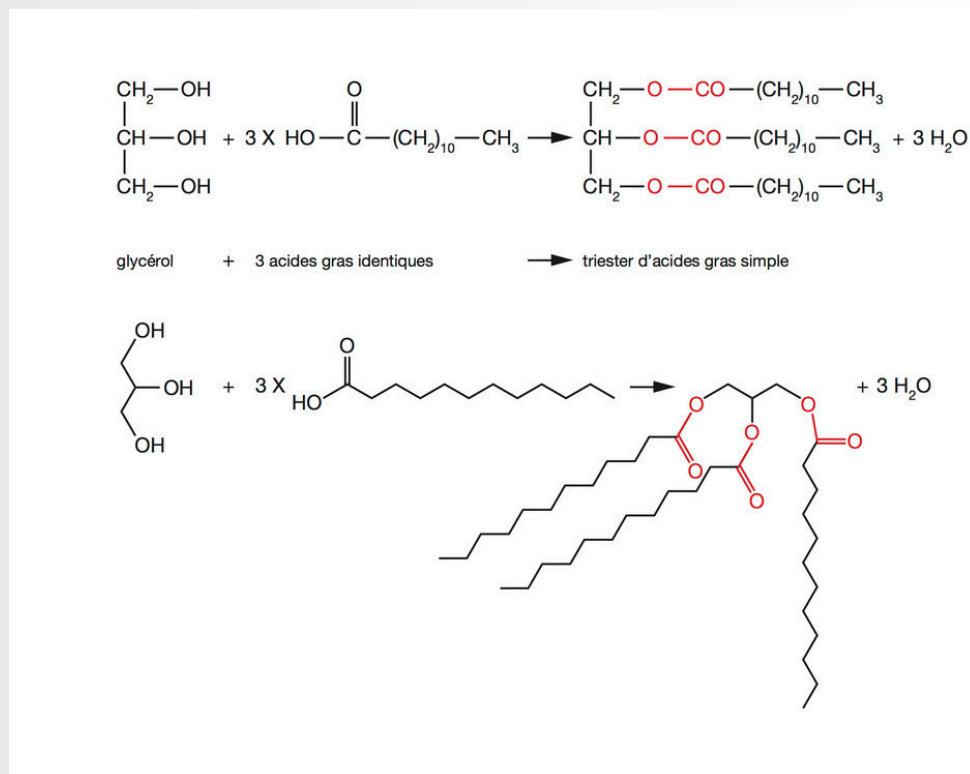


Figure 1.3 Overall esterification equation for triglyceride formation. Intermediate steps are not shown. Adapted from Segarra et al. (2014).

Esterification “neutralizes” the alcohol functions, making triglycerides completely hydrophobic. As a result, they accumulate as large lipid droplets in the cytosol, known as **oleosomes**. In some species, these lipid reserves are also found in specialized plastids called **oleoplasts**. It should be noted that these lipid droplets also contain proteins.

2.1.3. Protein reserves

Aleurone

Plant storage proteins often occur in the form of granules bounded by the tonoplast (vacuolar membrane), known as aleurone grains (Figure 01.4). Aleurone grains are mainly found in seeds; a typical example is the castor bean seed (*Ricinus communis*), although it is both an oilseed and a protein-rich seed.

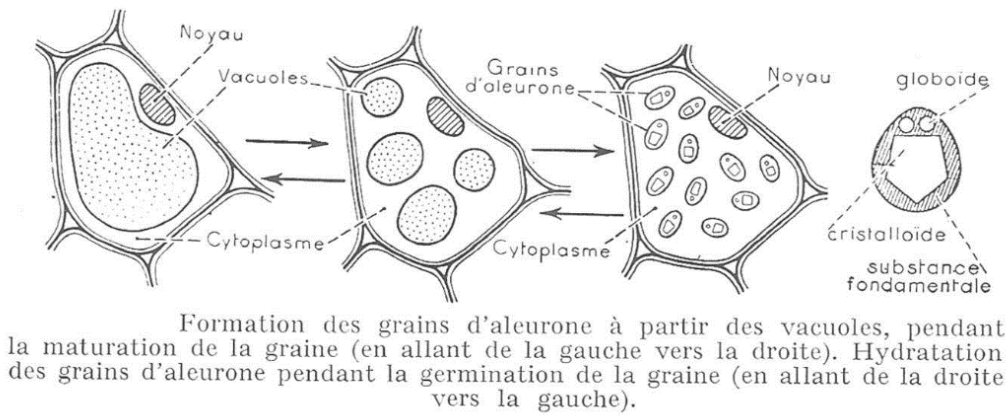


Figure 1.4 Aleurone grains in the castor bean seed. Adapted from Camefort & Boué (1980).

Note

In some cereals, such as wheat, the endosperm contains a significant protein fraction, which forms gluten. Gluten is a complex mixture of storage proteins, primarily gliadins and glutenins, that are responsible for the elastic and cohesive properties of dough. These proteins not only serve as a source of nitrogen and amino acids for the germinating seed but also have major economic importance, particularly in the baking industry, where they determine the texture, extensibility, and water-holding capacity of bread and other baked products.

2.2. The main reserve tissues and organs

2.2.1. Reserve tissues

Location of Plant Storage Reserves

Plant storage reserves are primarily located within specialized tissues adapted for the accumulation of carbohydrates, lipids, and proteins. One key site is **specialized parenchyma**, often referred to as **storage parenchyma**. These cells typically have large vacuoles or cytoplasmic regions dedicated to reserve accumulation and are found in various organs such as roots, tubers, stems, and seeds.

Another important site is the woody or **phloem parenchyma**, which forms part of the secondary vascular system. In these tissues, cell walls may contain variable amounts of lignin, providing mechanical support while still allowing the storage and mobilization of reserves. These cells are particularly abundant in the wood-phloem rays, which facilitate the radial transport of nutrients and reserves between the xylem and phloem. Such strategic localization ensures that reserves are both protected and accessible for growth, development, and germination.

2.2.2. Storage Organs

The non-chlorophyllous regions of a plant function as heterotrophic organs within an otherwise autotrophic organism. While the plant as a whole is capable of photosynthesis and autotrophic carbon fixation, these specialized organs such as roots, tubers, bulbs, rhizomes, and seeds—cannot synthesize carbohydrates independently. Instead, they rely on the transport of photosynthetically produced compounds, mainly sugars, from photosynthetic tissues (leaves and green stems) to accumulate reserves.

- These heterotrophic organs serve multiple critical roles:
- act as storage sites for carbohydrates, lipids, and proteins,
- providing energy and building blocks for growth and development;
- enable the plant to survive periods of environmental stress, such as winter dormancy or drought; and
- support reproduction, particularly in seeds and storage tubers.

In this way, the plant integrates autotrophic and heterotrophic functions, coordinating the production, transport, and storage of essential compounds to ensure survival, adaptation, and reproduction.

Seeds

Seeds accumulate reserves in a form that is easily stored and preserved, ensuring the future development of the embryo. These reserves also represent an important source of food for animals (granivorous diet) and for humans, who consume them as cereals and legumes.

Depending on their composition, seeds can be classified according to the type of stored reserves:

- **Starchy seeds** store mainly carbohydrates, particularly starch, examples include rice, millet, sorghum, maize, and wheat.
- **Oil seeds** store primarily lipids, examples include peanut, sunflower, and rapeseed.
- **Protein-rich seeds** store mostly storage proteins, examples include cowpea (*Vigna unguiculata*), bean, lentil, and pea.

Bulbs:

A bulb is a vertical underground shoot composed of a short stem surrounded by modified leaves, which serve as storage organs for nutrients. These specialized leaves accumulate reserves, primarily carbohydrates and, in some species, proteins, enabling the plant to survive periods of dormancy, such as winter or dry seasons. Bulbs provide the energy required for rapid regrowth and flowering when favorable conditions return. Common examples include onion (*Allium cepa*), garlic (*Allium sativum*), and tulip (*Tulipa* spp.). In addition to their biological role, bulbs have significant economic importance, serving as staple vegetables, horticultural crops, and sources of flavoring and medicinal compounds.

Tubers

A tuber is a storage organ, generally located underground, that ensures the survival of plants during unfavorable conditions such as winter. These organs become swollen due to the accumulation of reserve substances, a process referred to as tuberization.

Tubers can originate from different plant structures:

- Roots, as in carrot (*Daucus carota*) and cassava (*Manihot esculenta*).
- Stem bases, as in kohlrabi (*Brassica oleracea* var. gongylodes).
- Both root and stem base, as in beetroot (*Beta vulgaris*) and radish (*Raphanus sativus*).

Tubers serve as important storage sites for carbohydrates, primarily starch, and sometimes proteins, providing energy for regrowth and reproduction in the following growing season. They also have significant economic value, being widely cultivated as staple foods and industrial raw materials.

Rhizomes

A rhizome is an underground stem, typically growing horizontally, found in certain perennial plants. Rhizomes function as storage organs, accumulating reserve substances such as starch or inulin, which provide energy for vegetative growth, regrowth after dormancy, and reproduction. Examples of plants with storage rhizomes include potato (*Solanum tuberosum*) and sweet potato (*Ipomoea batatas*). These organs not only support the plant's survival during unfavorable conditions but also have significant economic importance, serving as staple foods and sources of industrially valuable carbohydrates.

Fruits:

Fruits often serve as storage organs, accumulating reserves either in the pulp (in fleshy fruits) or within the seeds (in dry fruits).

In fleshy fruits, such as mango (*Mangifera indica*), apple (*Malus domestica*), or tomato (*Solanum lycopersicum*), the edible pulp is rich in carbohydrates mainly sugars such as glucose, fructose, and sucrose which provide energy for seed development and act as an attractant for animals that aid in seed dispersal. Fleshy fruits may also contain small amounts of lipids and organic acids, contributing to nutritional value and preservation.

In dry fruits, the storage reserves are primarily concentrated in the seeds. Examples include nuts and legumes, where carbohydrates (starch), lipids (oil), and proteins serve as energy and nutrient sources for the developing embryo. These reserves are crucial for germination and early seedling growth, providing the metabolic energy necessary before the plant can photosynthesize independently.

Fruits, therefore, not only play a key role in reproduction and dispersal but also have significant economic and nutritional importance for humans and animals, being major sources of food, oils, and other plant-derived products.



3. Dietary Fibers and Plant-Derived Texturizing Agents

3.1. Dietary fibers

Definition

Dietary fibers refer to all components of food that are resistant to digestion by the enzymes of the human gastrointestinal tract. They include non-starch polysaccharides such as cellulose, hemicelluloses, pectins, gums, and mucilages, as well as certain lignin components. Dietary fibers play a crucial role in maintaining gastrointestinal health, regulating bowel movements, and influencing the absorption of nutrients.

3.1.1. Constituents of Dietary Fibers

Dietary fibers are primarily composed of plant-derived polyholosides consisting of multiple monosaccharide units—alongside a smaller proportion of non-carbohydrate plant components, such as lignin and polyphenols. These complex structures are largely resistant to human digestive enzymes, which is why they contribute to the fiber content of foods.

a) Insoluble Dietary Fibers

Insoluble fibers are truly fibrous in nature and are primarily found in the plant cell walls. The main constituents of these fibers are:

- **Cellulose:** A linear polymer composed of β -D-glucopyranose units linked by $\beta(1\rightarrow4)$ glycosidic bonds. Cellulose forms strong microfibrils that provide structural rigidity to plant cell walls.
- **Hemicelluloses:** These are heterogeneous polysaccharides, often composed of xylose units and other sugars, that interact with cellulose and contribute to the overall strength and flexibility of the cell wall.
- **Lignin:** Unlike cellulose and hemicelluloses, lignin is a non-carbohydrate component of the cell wall, consisting of phenylpropanoid units. It is highly hydrophobic and provides additional mechanical support and resistance to microbial degradation.

These insoluble fibers do not dissolve in water but contribute significantly to fecal bulk and facilitate the passage of material through the gastrointestinal tract. Their structural complexity, combining polysaccharides and phenolic compounds, makes them particularly important for both plant physiology and human nutrition.

b) Soluble Dietary Fibers

Soluble fibers differ from insoluble fibers in that they are not structurally fibrous but are highly hydrated carbohydrate substances capable of forming viscous gels, also called hydrocolloids. These fibers play important physiological roles in slowing nutrient absorption, modulating blood glucose, and lowering cholesterol levels.

Key components of soluble fibers include:

- **Pectins:** These are heterogeneous polysaccharides found in the plant cell wall, primarily composed of galacturonic acid residues. Pectins have a strong water-binding capacity and can form gels, which contribute to the texture of fruits and other plant-based foods.
- **Phytic acid:** Also known as inositol hexaphosphate, phytic acid is concentrated in the seed coats (testa) of many plants. While not forming gels like pectins, phytic acid binds minerals such as calcium, magnesium, and iron, influencing their bioavailability. It is therefore considered a functional component of plant-based foods.

Soluble fibers, through their gel-forming ability and water retention, complement insoluble fibers by regulating gastrointestinal function and providing beneficial effects for human health. Their chemical diversity—from pectic polysaccharides to phytic acid—illustrates the complex functional roles of plant-derived hydrocolloids in both nutrition and food technology.

c) Major Sources of Dietary Fibers

Cereals are the primary sources of dietary fiber in the human diet. For example, wheat bran contains approximately 40–45% fiber by mass, while whole wheat bread provides about 7–8% fiber by mass.

Legumes are also significant contributors; for instance, dry beans (such as white beans *Phaseolus vulgaris*) contain roughly 8–10% fiber by mass.

It is important to note that dried fruits are particularly concentrated in dietary fibers: prunes provide around 7% fiber by mass, and dates contain approximately 9% fiber by mass.

These examples illustrate how both cereal-based and plant-derived foods contribute to dietary fiber intake, supporting digestive health and nutritional balance.

3.2. Texturizing Agents (Food Additives)

Definition

A food texturizer is an additive used to modify the physical properties of a food product without significantly altering its taste. These agents are essential in the food industry to control texture, consistency, and stability. Major categories of texturizing agents include:

- **Thickeners:** Increase the viscosity of liquids or semi-liquids, improving mouthfeel and suspension of ingredients. Examples include starches, guar gum (E 412), and locust bean gum (E 410).
- **Gelling agents:** Provide a gel-like consistency to foods, creating a semi-solid structure. Examples include pectins, agar, and carrageenan.
- **Stabilizers:** Enhance the physical stability of food products, preventing separation of components during storage or processing. They are often combined with emulsifiers and thickeners.
- **Emulsifiers:** Improve the dispersion and suspension of immiscible ingredients, such as oil and water, ensuring a uniform texture. Examples include lecithins and mono- and diglycerides.
- **Binders:** Aggregate solid particles, often in powdered form, into cohesive structures, improving product integrity. Common in processed foods, bakery products, and meat analogues.

These functional agents are often derived from plant polysaccharides (e.g., gums, starches) or from other natural sources, linking plant biochemistry to food technology. Their proper use allows manufacturers to achieve desirable texture, consistency, and shelf stability in a wide range of products.

Among the most widely used texturing agents in the food and pharmaceutical industries are:

3.2.1. Starch:

Starch is a storage carbohydrate synthesized in photosynthetic plant cells. It serves as the primary energy reserve, allowing plants to store the products of photosynthesis for later use in growth, reproduction, or survival under unfavorable conditions. Starch is typically accumulated in chloroplasts and specialized storage plastids called amyloplasts, where it forms dense granules.

3.2.2. Gum Arabic (Acacia Gum):

Gum arabic, also known as acacia gum, is a complex plant-derived polysaccharide obtained from the exudates of various *Acacia* species, primarily found in African countries such as Senegal, Sudan, and Nigeria. This natural gum is highly soluble in water and has an exceptional capacity to form viscous solutions and stabilize emulsions, which makes it one of the most versatile food texturizing agents.

In the food industry, gum arabic is widely used as a thickener, stabilizer, and emulsifier, especially in beverages, confectionery, and bakery products. Its ability to interact with other polysaccharides, proteins, and lipids allows manufacturers to modify texture, improve mouthfeel, and stabilize suspensions without significantly altering flavor.

3.2.3. Pectins:

Pectins are acidic polysaccharides primarily extracted from fruits, especially citrus fruits (oranges, lemons) and apples. They are highly valued in the food industry for their ability to form gels, thicken, and stabilize products, making them essential gelling agents and texturizers.

Chemically, pectins are composed of galacturonic acid units, which can interact with water and other components to produce viscous solutions and gel networks. Their gel-forming property is widely used in jams, jellies, fruit preserves, and dairy products.

In addition to their technological functions, pectins contribute soluble dietary fiber, supporting gastrointestinal health and complementing other plant-derived fibers in the human diet. This dual role as a functional food ingredient and texturizer highlights the importance of pectins in both nutrition and food technology.

3.2.4. Other Plant-Derived Gums

In addition to gum arabic and pectins, several other plant-derived polysaccharides are widely used as food texturizers:

Guar gum (E 412): Extracted from the endosperm of *Cyamopsis tetragonoloba* seeds, guar gum is rich in galactomannans. It has a high water-binding capacity, forming viscous solutions that act as thickeners, stabilizers, and emulsifiers in sauces, bakery products, and dairy applications.

Xanthan gum (E 415): Although produced by the bacterium *Xanthomonas campestris*, its substrate is derived from plant sugars. Xanthan gum forms highly viscous solutions and stable gels, and is widely used in sauces, dressings, and gluten-free products.

Tragacanth gum (*Astragalus* spp.): A natural gum obtained from the exudate of *Astragalus* species. It is used as a thickener, stabilizer, and emulsifier in confectionery, bakery, and pharmaceutical formulations due to its high water-binding and gel-forming properties.

Locust bean gum (carob flour, E 410): Extracted from the seeds of *Ceratonia siliqua*, this gum consists of galactomannans and is used as a thickener, stabilizer, and synergistic gelling agent in dairy and dessert products.

These plant-derived gums demonstrate the functional versatility of polysaccharides in food technology. Their ability to modify viscosity, stabilize emulsions, and form gels makes them essential ingredients for texture control, while some also contribute soluble dietary fiber, linking nutrition and industrial functionality.

4. Plant-Derived Fibers: Beyond Nutrition

The value of plant-derived fibers extends far beyond their nutritional role. These fibers are multifunctional materials with properties that make them attractive for various industrial and environmental applications. Unlike synthetic fibers, natural fibers offer specific advantages:

- Mechanical performance: High tensile strength and flexibility, useful in composites and textiles.
- Low energy production requirements: Their extraction and processing demand significantly less energy compared to synthetic counterparts.
- Sustainable end-of-life management: Plant fibers can be incinerated for energy recovery or biodegraded, reducing environmental impact.

Plant fibers can be obtained from diverse botanical sources, each with unique properties:

- Stem fibers: flax (*Linum* spp.), hemp (*Cannabis sativa*)
- Leaf fibers: sisal, agave
- Fruit fibers: coconut coir
- Grasses and herbs: *Arundo donax*
- Cereal residues: wheat straw
- Wood fibers: softwood and hardwood species
- Pseudo-stems: banana plant

These fibers are increasingly used in composite materials, construction, packaging, automotive parts, and bio-based textiles, demonstrating their versatility. By combining biological properties with technological applications, plant fibers illustrate a sustainable approach to materials science, offering both performance and ecological benefits. See main and simplified classification of natural fibers of Figure 1.5

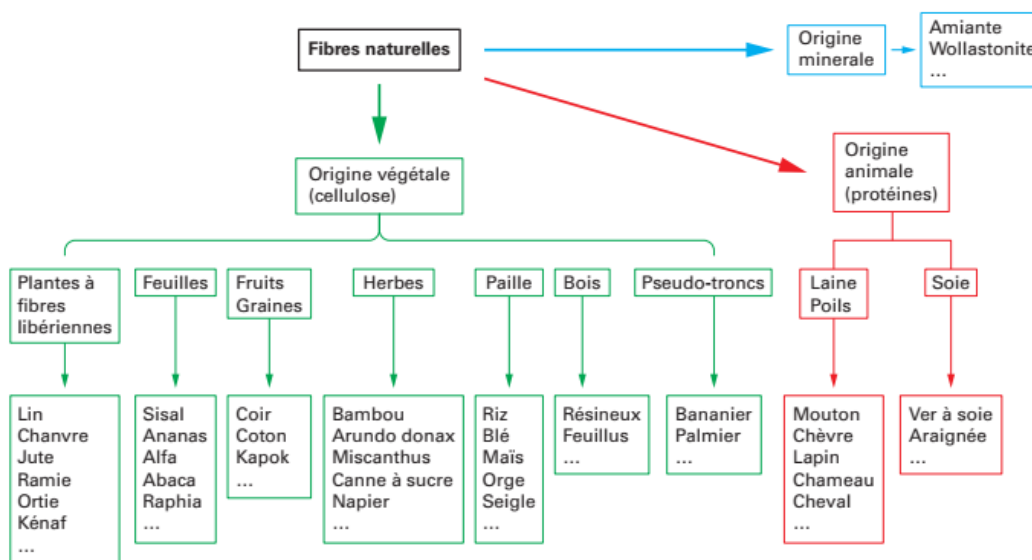


Figure 1.5 Simplified classification of natural fibers according to their origin, with examples.

5. Wood

Wood is one of the most important natural resources provided by plants, playing a crucial role in both human society and industrial development. Beyond its ecological functions in forests, wood has been valued for millennia for its mechanical strength, versatility, and renewability.

As a material, wood is used in a wide range of applications: construction, furniture, paper production, energy (firewood, biomass), and crafts.

Moreover, wood is a renewable resource that can be sustainably managed through responsible forestry practices. By combining economic value, ecological significance, and technological applications, wood exemplifies a natural material with multifunctional uses, linking biological, industrial, and environmental perspectives.

5.1. Chemical Composition of Wood

The cell wall of wood, like that of other plant tissues, is composed of four major types of constituents, each contributing to its structural and functional properties:

- **Cellulose** (40–50% of total mass): A linear polymer of β -D-glucose units, cellulose forms microfibrils that provide tensile strength and structural integrity to the wood cell wall.
- **Hemicelluloses** (20–35%): Heterogeneous polysaccharides that interact with cellulose microfibrils, contributing to the flexibility and cohesion of the cell wall matrix.
- **Lignin** (15–35%): A complex aromatic polymer that cements cellulose and hemicelluloses, providing rigidity, hydrophobicity, and resistance to microbial degradation.
- **Extractives** (3–10%): A diverse group of low-molecular-weight compounds, including resins, tannins, and oils, which influence color, durability, and decay resistance.

The supramolecular structure of the wood cell wall (Figure 1.6) illustrates the arrangement of cellulose microfibrils embedded in a matrix of hemicelluloses and lignin, forming a composite material with remarkable mechanical strength, stability, and functional versatility.

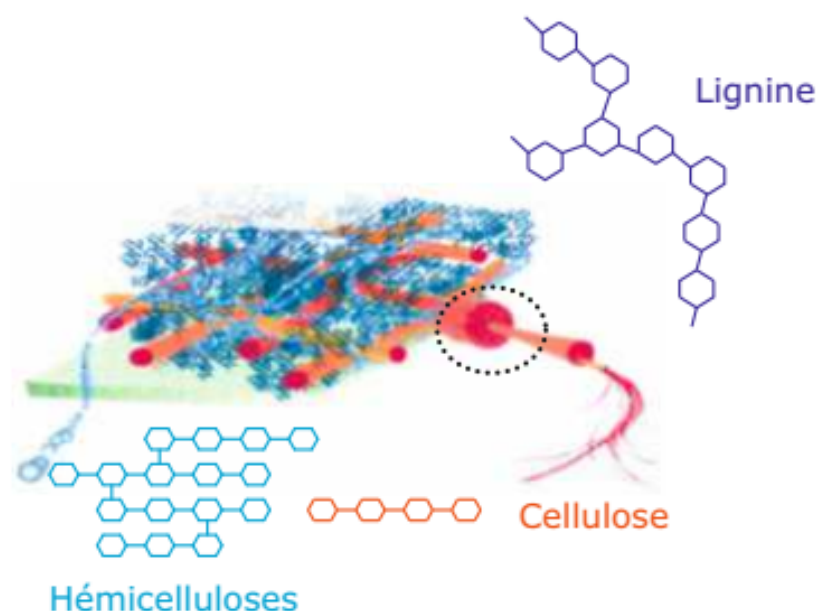


Figure 1.6 Structure wood cell wall

5.2. Lignocellulosic Biorefinery

The wood industry generates substantial by-products with significant economic and industrial value, including cellulose, hemicellulose, and lignin. Rather than being treated as waste, these components can be valorized through integrated processes in what are called lignocellulosic biorefineries.

A lignocellulosic biorefinery is a facility designed to fractionate plant biomass into its constituent polymers and convert them into high-value products. For example:

- Cellulose can be transformed into bioethanol, nanocellulose, paper, and cellulose derivatives.
- Hemicelluloses can be hydrolyzed into sugars for fermentation, or used to produce xylitol, furfural, and other chemicals.
- Lignin, traditionally considered a low-value by-product, can be converted into aromatic chemicals, adhesives, bioplastics, or used as a renewable fuel.

By integrating chemical, enzymatic, and microbial processes, lignocellulosic biorefineries enable efficient use of all biomass components, minimizing waste and contributing to a circular bioeconomy. This approach exemplifies how forestry and plant-based industries can evolve from traditional raw material production to high-value, sustainable biochemical and material production. See Figure 1.7

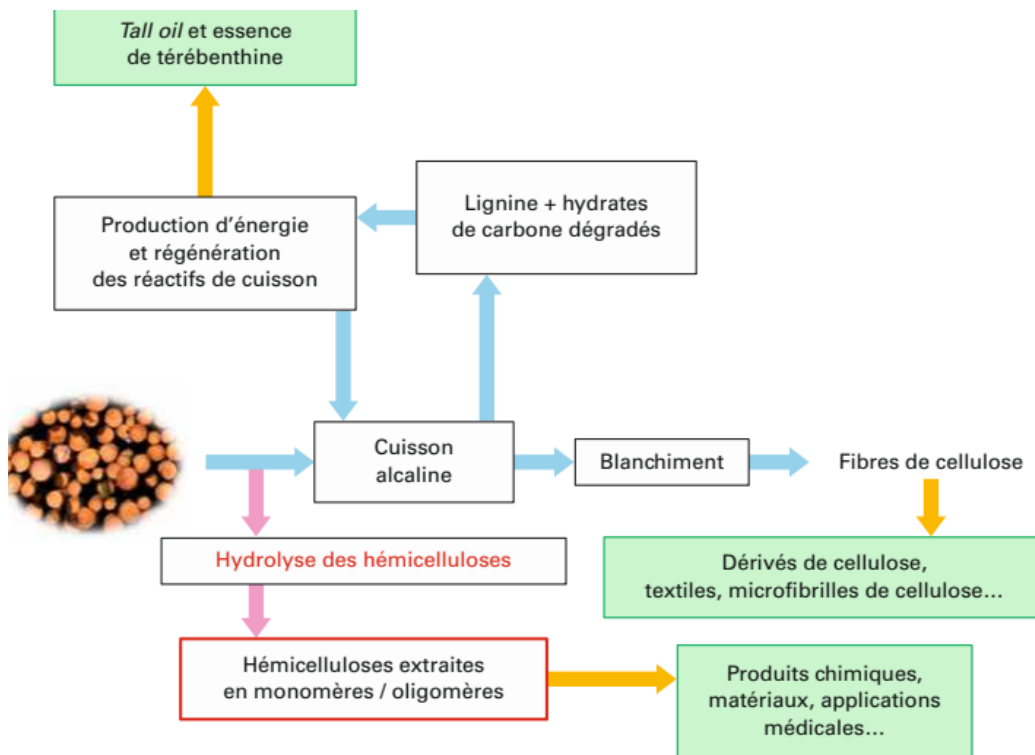


Figure 1.7 Lignocellulosic biorefinery integrated into a cellulose production plant for the simultaneous production of cellulose and sugars

6. Paper Production

The production of pulp aims to break down wood into its constituent fibers while preserving cellulose, which forms the essential component of paper fibers. To achieve this, it is necessary to remove or chemically modify certain wood components, such as lignin and extractives including resins, tannins, and other low-molecular-weight compounds.

The **delignification** process not only enhances the whiteness and durability of the pulp but also ensures that the cellulose fibers retain their mechanical strength and flexibility, essential for high-quality paper production. Various mechanical, chemical, and enzymatic methods are used, depending on the desired pulp properties and environmental considerations.

Through this process, the wood is transformed from a complex lignocellulosic material into a versatile raw material that can be further processed into paper, cardboard, and other cellulose-based products, highlighting the industrial importance of cellulose preservation and selective component removal.

6.1. Lignolytic Microorganisms

A wide variety of microorganisms, including both bacteria and fungi, are capable of degrading lignocellulosic compounds present in plant materials. These organisms are collectively referred to as lignolytic or lignin-degrading microorganisms.

Lignolytic microorganisms play a crucial role in nature's carbon cycle, breaking down complex polymers such as lignin, cellulose, and hemicellulose into smaller molecules that can be further metabolized. Fungi, particularly white-rot and brown-rot fungi, are among the most efficient lignin degraders, producing oxidative enzymes such as lignin peroxidases, manganese peroxidases, and laccases. Certain bacteria also exhibit lignin-degrading activity, often through cooperative enzymatic systems.

The study and application of these microorganisms are of considerable industrial interest, as they can be used in biopulping, biobleaching, bioethanol production, and the valorization of lignin-rich residues from agriculture and forestry. By harnessing their enzymatic potential, lignolytic microorganisms provide a biotechnological route for sustainable utilization of lignocellulosic biomass.

6.1.1. Lignolytic Bacteria

Lignolytic bacteria are a diverse group of microorganisms capable of degrading lignin and other complex lignocellulosic compounds in plant biomass. They play a crucial role in biodegradation, bioconversion, and nutrient cycling, and have significant potential for industrial applications.

Key representatives of lignolytic bacteria include:

- **Actinomycetes:** genera such as *Nocardia*, *Streptomyces*, *Thermomonospora*, *Micromonospora*, and *Corynebacterium*, known for their filamentous growth and production of extracellular lignin-degrading enzymes.
- **Pseudomonadaceae** family: including *Pseudomonas* and *Xanthomonas* species, which exhibit versatile metabolic pathways enabling them to attack various lignin-derived compounds.
- Other genera: certain species of *Bacillus*, *Aeromonas*, and *Acinetobacter*, which can participate in lignin breakdown and co-metabolism of lignocellulosic residues.

These bacteria utilize enzymatic systems, such as laccases and peroxidases, to oxidize lignin and release simpler molecules, which can be further converted into biofuels, bioplastics, or value-added chemicals. Studying lignolytic bacteria is therefore essential for biotechnological strategies aimed at sustainable utilization of lignocellulosic biomass.

6.1.2. Lignolytic Filamentous Fungi

a) Soft-rot fungi

Among lignolytic microorganisms, filamentous fungi play a key role in the degradation of plant biomass, particularly lignocellulosic materials. One important group is the soft-rot fungi, which primarily attack polysaccharides such as cellulose, hemicelluloses, and pectins rather than lignin. Soft-rot fungi are represented by a variety of genera, including:

Chaetomium, *Xylaria*, *Alternaria*, *Cephalosporium*, *Cytospora*, and *Pestalotia*. These fungi produce enzymes such as cellulases, hemicellulases, and pectinases, which allow them to efficiently decompose the carbohydrate matrix of the plant cell wall.

Soft-rot fungi are particularly important in humid environments or wood with high moisture content, where they contribute to biodegradation, nutrient recycling, and natural biomass turnover. Their enzymatic systems are also studied for industrial applications, including biopulping, bioethanol production, and conversion of agricultural residues into value-added products.

i Brown-Rot Fungi

Brown-rot fungi primarily degrade cellulose and hemicelluloses, while leaving most of the lignin largely intact, which gives the characteristic brown color to the decayed wood. This selective degradation allows brown-rot fungi to rapidly weaken the structural integrity of wood without extensively breaking down lignin.

Brown-rot fungi are mainly **Basidiomycetes**, although some **Ascomycetes** also exhibit brown-rot characteristics. These fungi produce cellulolytic and hemicellulolytic enzymes, such as endoglucanases, exoglucanases, and xylanases, often complemented by non-enzymatic oxidative mechanisms that facilitate polysaccharide depolymerization.

Brown-rot fungi play a key ecological role in forest ecosystems, contributing to carbon cycling and nutrient release, and are also of interest in biotechnological applications, such as biopulping, bioethanol production, and selective carbohydrate extraction from lignocellulosic biomass.

ii White-Rot Fungi

White-rot fungi are unique among microorganisms, as they are the only organisms capable of fully mineralizing lignin from higher plants into CO₂ and H₂O, while also degrading cellulose and hemicelluloses. This comprehensive lignocellulose-degrading ability makes them crucial in ecosystem carbon cycling and in biotechnological applications.

Notable white-rot fungi belong to the **Basidiomycetes** and include species such as *Phanerochaete chrysosporium*, *Trametes versicolor*, *Phlebia radiata*, and *Pycnoporus cinnabarinus*. These fungi produce an array of ligninolytic enzymes, including lignin peroxidases, manganese peroxidases, and laccases, which work synergistically with cellulases and hemicellulases to decompose all components of the plant cell wall.

White-rot fungi are extensively studied for industrial and environmental applications, including biopulping, biobleaching, bioethanol production, and the valorization of lignin-rich residues. Their unique enzymatic machinery also inspires biotechnological innovations aimed at sustainable utilization of lignocellulosic biomass.

* *

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End-of-Chapter Questions

- Name three main types of plant storage organs.
- What is the main function of tubers in plants?
- How do seeds serve as energy reserves?
- Which plant organs are commonly used to produce textile fibers?
- Give one example of a fiber and its source plant.
- Why are bast fibers important in the textile industry?
- Which plant organs are typically used for sugar production?
- Give one example of a starch-rich plant and its use.
- How are sugars and starches connected to the food and beverage industry?
- Name one oil-producing plant organ.
- Give an example of an industrial use of plant oils.
- How do lipids from seeds contribute to energy and industrial applications?
- Which plant organs are used in the paper industry?
- Name one use of tubers or grains in the refinery or biofuel industry.
- Why is understanding plant storage organs important for economic exploitation?

Secondary metabolism products and their uses


II

By the end of this chapter, the student will be able to

- Identify and classify the major groups of plant secondary metabolites based on their chemical structures.
- Describe the fundamental physicochemical properties and chemical characteristics of these metabolites.
- Summarize the various biological activities associated with different classes of plant compounds.

1. Introduction

Nature is the immense source of chemical compounds or substances usually acknowledged as natural products. Plants are the considerable source of an inestimable diversity of natural products with manifold chemical structures and functionalities. These natural compounds have various healthcare benefits and are commonly termed as the primary metabolites (PPMs) and secondary metabolites (PSMs). Biogenically, there are basically four main classes of secondary metabolites: phenolics and polyphenolics, terpenes, nitrogen-containing alkaloids, and sulfur-containing compounds. The functional groups and other structural features present in a molecule are accountable for delivering a variety of characteristics including therapeutic applications and the solubility and stability of the molecules. The structural features of compounds useful to understand the relations between their molecular structures and biological or pharmacological activities are attributed to being responsible for arousing a target biological effect in the organism. This chapter will delineate the chemistry, classification, physicochemical properties, and numerous biological activities of plant secondary metabolites. In order to develop the new derivatives of therapeutic value, the present chapter would be useful for medicinal chemists to design and introduce new chemical groups into these biomedical compounds and to explore their biological effects.

2. Plant Secondary Metabolites: An Introduction of Their Chemistry and Biological Significance

Plant secondary metabolites are diverse organic compounds not essential for basic growth but crucial for survival, defense, and interaction, acting as attractants (pigments, scents), repellents (toxins, antimicrobials) against pests, and aiding in stress adaptation, with key groups including alkaloids, terpenoids, and phenolics, forming the basis for many medicines, flavors, and colors.

2.1. Importance and main Groups of Secondary Metabolites.

Importance of Secondary Metabolites.

secondary metabolites were earlier regarded as waste products because of their adaptive therapeutic significance not known earlier, nowadays, their numerous functions in plants and human health along with therapeutic roles have been evaluated and explored as a source of natural drugs, allelopathic agents, anticancer agents, antibiotics, flavoring agent, perfuming agent, pigments, signal molecules, UV protectants. Besides, PSMs bestow the various functions and benefits to the plants such as to attract the pollinators and seed dispersers, help in the recovery from injury, protect from ultraviolet radiation, and enhance the defense against pathogens, diseases, and herbivores. PSMs have been the source of lead compounds for the development of drugs and alternative therapeutics to treat/prevent the broad spectrum of human health problems and diseases such as neurodegenerative diseases, cancer, inflammation, infectious and blood vessel diseases, etc. Over the last few decades, plant secondary metabolites attracted the attention of researchers, scientists, academicians, and industrialists, owing to their multifaceted role and contributions in plants (specific odors, color, and taste as well defense system) and in human nutrition along with the commercial importance as cosmetics, drugs, dyes, polymers, herbicides, insecticides

Main classes

The plant secondary metabolites are biogenically divided into main four classes (**phenolics** and **polyphenolics**, **terpenes**,

and **nitrogen-containing (alkaloids)** and **sulfur-containing compounds** (Figure 2.1) and further subdivided into subclasses on the basis of their molecular structure, substituent groups, functional groups, and linkage types with substitution pattern. These compounds are widely distributed in the plant realm and ubiquitous in plant-based foods. The infinite combination of structural features of PSMs such as complex and specifically arranged aromatic rings, chiral centers, and the number and the ratio of heteroatoms might be essential and responsible for their interaction with one or more compounds of living tissues and showing an effect on the human health as the starting point for drug discovery and novel synthetic drug developments. PSMs belong to the different subclasses of compounds on the basis of chemical structures, structural features, and compositions (Figure 2.2)

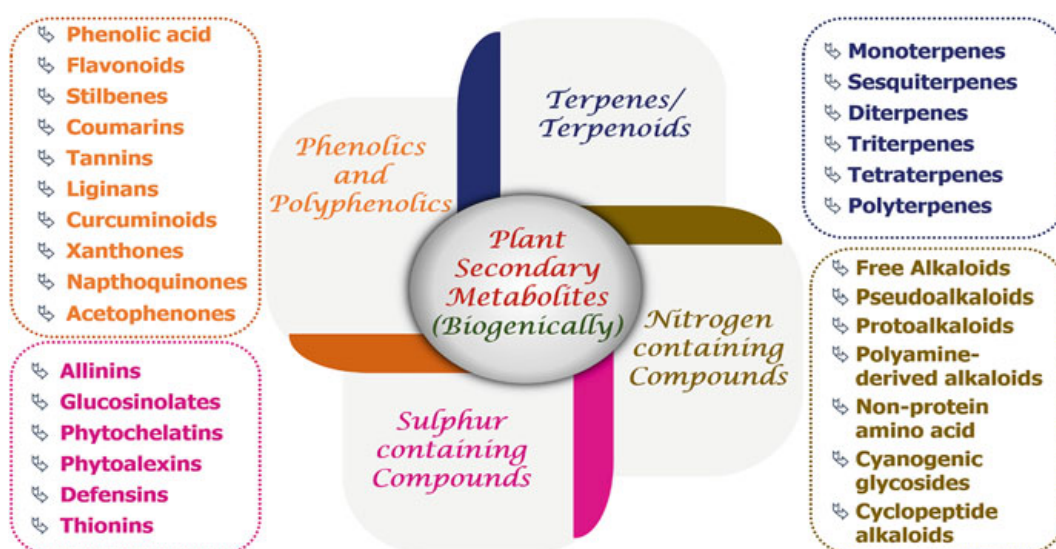


Figure 2.1 The general classification of plant secondary metabolites into four major categories and

2.2. Phenolics and Polyphenolics

Phenolics and polyphenolics are diverse plant secondary metabolites characterized by at least one aromatic ring with a hydroxyl group. Widely distributed in foods like fruits, vegetables, and beverages, they are highly valued for their health benefits, including the prevention of cardiovascular and neurodegenerative diseases and cancer. They are primarily classified into flavonoids and non-flavonoids based on their chemical structure, complexity, and functional groups. (Figure 2.2)

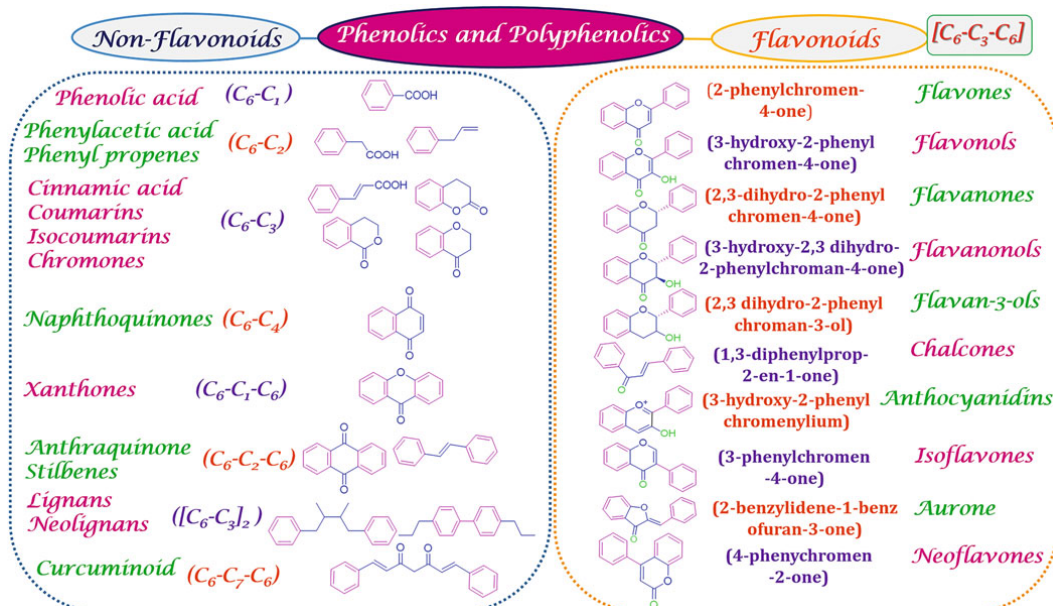


Figure 2.2 The most adopted classification of phenolics and polyphenolics: flavonoids and non-flavonoids. The different subclasses of flavonoids and non-flavonoids with their common nucleus carbon skeleton

2.2.1. Flavonoids

a) Importance and Therapeutic Significance

Flavonoids are the most prevalent class of polyphenols (comprising up to 60% of the total). They are widely studied due to their "multi-target" biological activities, such as antioxidant, anti-inflammatory, anticancer, and antimicrobial effects. Consequently, flavonoid-rich diets are essential for preventing and treating various human ailments.

b) Core chemical structure

The structural hallmark of flavonoids is the $C_6-C_3-C_6$ carbon skeleton (diphenylpropane). This system consists of: Two benzene rings (A and B). A central three-carbon unit (Ring C), which is usually a heterocyclic pyran ring. Note on variations: Some specific groups deviate from this rule, such as Chalcones (which have an open-chain structure instead of Ring C) and Aurones.

c) Classification Criteria

Flavonoids are divided into subclasses (e.g., flavonols, flavones, isoflavones, anthocyanidins) based on two main factors: The oxidation level of Ring C. The substitution pattern of the skeleton. The vast diversity of individual compounds is determined by the specific positions of hydroxyl ($-OH$) and methoxy ($-OCH_3$) groups on rings A and B.

2.2.2. Non-flavonoids

a) Overview and Health Impact

Non-flavonoids are a structurally diverse group of plant secondary metabolites. Like flavonoids, they are essential for human health, significantly reducing the risk of chronic diseases such as Alzheimer's, cancer, diabetes, and cardiovascular conditions. In plants, they contribute to nutritional value, sensory properties (taste /color), and aroma.

b) Key Structural Classes

Non-flavonoids are primarily classified by their carbon skeletons and the arrangement of their aromatic rings

i Phenolic Acids

The most common forms, often bound to cell walls (cellulose/lignin)

- Hydroxybenzoic acids (C_6-C_1 skeleton)
- Hydroxycinnamic acids (C_6-C_3 skeleton)

ii Phenylpropenes

(C_6-C_3): Volatile compounds responsible for the distinct flavor and aroma of spices and herbs.

iii Benzopyrones

(C_6-C_3): Includes Coumarins, Isocoumarins, and Chromones. They possess a benzopyrone nucleus and exhibit strong antioxidant and antimicrobial properties.

iv Quinones

Includes Naphthoquinones (C_6-C_2 fused rings) and Anthraquinones ($C_6-C_2-C_6$). These are often used as natural dyes due to their intense pigmentation.

v Large Skeletons

($C_6-C_n-C_6$):

Stilbenes : Based on a 1,2-diphenylethylene structure ($C_6-C_2-C_6$)

Xanthenes : A tricyclic system ($C_6-C_1-C_6$).

Curcuminoids : Heptanoid compounds ($C_6-C_7-C_6$), famous for the therapeutic properties of Turmeric (*Curcuma longa*).

vi Lignans and Neolignans

Dimers of phenylpropane units (C_6-C_3 dimers). They differ based on the type of linkage (e.g., β - β' linkage in lignans).

2.2.3. Phenolics and Polyphenolics: Applications

a) Industrial Application: Leather Tanning and Adhesives

Example

Tannins (a major group of polyphenols) are used extensively in the leather industry. They react with the proteins in animal hides to stabilize them, preventing decay and turning skins into durable leather. Additionally, certain phenolic resins are used as high-strength adhesives in wood manufacturing (like plywood).

b) Medical Application: Diagnostic Tools and Biomarkers

Example

Quercetin and other polyphenols are used in medical research as fluorescent probes or markers to study oxidative stress in cells. Because they react specifically with Reactive Oxygen Species (ROS), they help doctors and researchers visualize damage in tissues related to aging or chronic inflammation.

c) Pharmaceutical Application: Cardioprotective and Venotonic Drugs

Example

Flavonoids (such as Diosmin or Hesperidin) are the active ingredients in pharmaceutical formulations used to treat chronic venous insufficiency and hemorrhoids. They strengthen capillary walls and improve blood flow, acting as "vasoprotective" agents.

d) Food Application: Natural Preservatives and Antioxidants

Definition

Rosmarinic acid (extracted from rosemary) or Tocopherols are added to processed foods (like oils, meats, and snacks) as natural antioxidants. They prevent lipid peroxidation (rancidity), thereby extending the shelf life of the product without the need for synthetic chemicals like BHT.

2.3. Nitrogen-Containing Compounds

Characteristics and Origin

Nitrogen-containing plant secondary metabolites (PSMs) are a vast group of compounds, most of which are synthesized from amino acids. Their structural diversity allows them to play critical roles in the plant's defense system and exhibit powerful biological effects in humans.

2.3.1. Alkaloids

General Characteristics and Distribution

Alkaloids represent one of the largest classes of secondary metabolites. They are defined by the presence of at least one nitrogen atom and are known for being highly biologically active.

- **Occurrence:** They are widespread in the plant kingdom, particularly in medicinal plant families, and concentrated in specific parts like leaves, bark, or roots.
- **Chemical State:** In nature, they are often found as water-soluble salts of organic acids (such as acetic or citric acid), esters, or glycosides.

- **Physical Properties:** They are typically isolated as crystalline, non-volatile, and odorless compounds.

Biosynthesis and Biological Role

- **Origin:** Alkaloids are biosynthesized from specific amino acid precursors, mainly lysine, tryptophan, and tyrosine.
- **Ecological Function:** They assist in plant survival by acting as protectors against pathogens and predators.
- **Pharmacology:** Their effect on humans (therapeutic, addictive, or toxic) depends on the dose, duration of exposure, and biological factors like age and sensitivity.

Structural Diversity

Alkaloids exhibit greater structural diversity than almost any other class of natural products. They are generally classified based on their carbon skeleton or their biochemical precursors.

Main Division: They are divided based on the location of the nitrogen atom into two groups:

- **Heterocyclic alkaloids:** (Nitrogen is part of the ring).
- **Non-heterocyclic alkaloids:** (Nitrogen is not part of the ring).

Note: The diverse structural features of these nitrogenous compounds, including subclasses like polyamines, are responsible for their specific biological effects (Figs. 2.3)

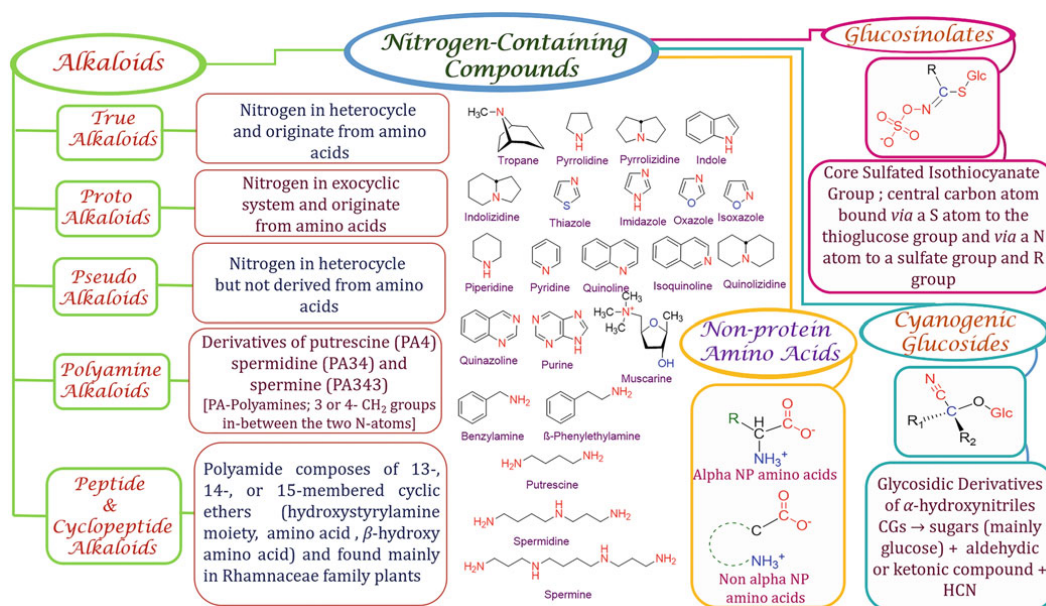


Figure 2.3 Different classes of nitrogen-containing plant secondary metabolites: alkaloids, cyanogenic glucosides, glucosinolates, and nonprotein amino acids and their common structural features

Alkaloids are categorized into five main groups based on their chemical structure and biological precursors (Fig. 2.3).

a) True Alkaloids (Heterocyclic Alkaloids)

These are the most common alkaloids.

- **Origin:** Derived directly from amino acids.

- **Structure:** The nitrogen atom is located inside a heterocyclic ring.
- **Examples:** Pyridine, Piperidine, Tropane, Quinoline, Isoquinoline, and Indole alkaloid.

b) Protoalkaloids (Non-heterocyclic Alkaloids)

- **Origin:** Also derived from amino acids.
- **Structure:** The nitrogen atom is not part of a ring; instead, it is found in a side chain (exocyclic system).
- **Key Feature:** They are often simpler molecules compared to true alkaloids.

c) Pseudoalkaloids

- **Origin:** Unlike the first two groups, these are not derived from amino acids. They come from non-amino precursors like terpenes or steroids.
- **Examples:** Terpenoidal (sterol) alkaloids and Tropolone alkaloids.

d) Polyamine Alkaloids

- **Structure:** They consist of an aliphatic chain containing two or more amino groups separated by methylene linkages.
- **Core Skeletons:** Based on polyamine functionalities such as putrescine, spermidine, and spermine.

e) Peptide and Cyclopeptide Alkaloids

- **Structure:** These contain two or more amino acids linked by peptide bonds.
- **Cyclization:** They often form macrocycles (13- to 15-membered rings) containing an aromatic unit. They can exist in both cyclic and linear forms.

2.3.2. Cyanogenic Glycosides

These are O- β -glycosides derived from both protein and nonprotein amino acids. They function as storage units for reduced nitrogen and sugar.

- **Mechanism of Action:** When plant tissue is damaged (e.g., by an herbivore), these compounds are degraded into α -hydroxynitriles.
- **Toxicity:** Through enzymatic hydrolysis, they release hydrogen cyanide (HCN), a potent toxin that protects the plant.

2.3.3. Glucosinolates

These are sulfur- and nitrogen-rich compounds, chemically described as β -thioglucosides.

- **Structure:** They consist of a central carbon atom bonded to :
 - A glycone group (via a sulfur atom).
 - A sulfonated oxime group (via a nitrogen atom).
 - A variable side chain (R-group).
- **Biological activity:** depends heavily on the specific structure of their side chains. They are responsible for the pungent taste in plants like mustard and radish.

2.3.4. Nonprotein Amino Acids

Unlike the 20 standard amino acids used to build proteins, these compounds exist freely or in specialized structures.

- **Nature:** They are C-alkylated analogs or substituted derivatives of protein amino acids.
- **Diversity:** Their variety comes from many substituents, including thiol, hydroxyl, imidazole, and guanidine groups.
- **Classification:** They are generally divided into two types:
 - Alpha (α) and
 - Non-alpha amino acids.

2.3.5. Nitrogen-Containing Compounds: Applications

a) Industrial Application: Natural Pesticides and Insecticides

Example

Nicotine and its derivatives are used in the agricultural industry as potent insecticides. They act as neurotoxins to pests. Additionally, some alkaloids are used as denaturants for alcohols or as bittering agents in various manufacturing processes to prevent accidental ingestion of toxic substances.

b) Medical Application: Diagnostic Imaging and Ophthalmology

Example

Atropine (an alkaloid derived from *Atropa belladonna*) is used in clinical settings to dilate the pupils (mydriasis) during eye examinations. It is also used as an emergency medical treatment to treat certain types of nerve agent poisoning or as a premedication to decrease saliva production before surgery.

c) Pharmaceutical Application: Analgesics and Anti-Cancer Agents

Morphine and Codeine are powerful pharmaceutical analgesics used for severe pain management. Furthermore, alkaloids like Vinblastine and Vincristine (from the Madagascar Periwinkle) are essential chemotherapy drugs used to treat various types of cancer, such as leukemia and Hodgkin's lymphoma.

d) Food Application: Stimulants and Flavor Enhancers

Example

Caffeine (found in coffee and tea) is widely used in the food and beverage industry as a natural stimulant. Another example is Capsaicin (the nitrogenous compound responsible for heat in chili peppers), which is used to provide pungency and "heat" in spicy food products and sauces.

2.4. Terpenes and Terpenoids

Definition : Building Blocks

Terpenes are primarily plant-derived hydrocarbons. Their most defining characteristic is that they are built from repeating isoprene units (2-methyl-1,3-butadiene, a 5-carbon unit).

- **Terpenes:** Simple hydrocarbons whose skeletons are exact multiples of isoprene units.
- **Terpenoids:** Modified terpenes that contain additional functional groups (usually oxygen) or have undergone structural rearrangements (e.g., removal or shifting of methyl groups).

Structural Diversity

Terpenoids exhibit a massive range of structures. They can be:

- **Acyclic:** Open-chain structures.
- **Cyclic:** Containing one or more rings (monocyclic, bicyclic, tricyclic, tetracyclic, or pentacyclic).
- **Functional Groups:** They often contain oxygen-based groups like alcohols, aldehydes, ketones, esters, and carboxylic acids.

Classification and Isomerism

Terpenes and terpenoids are classified based on the number of isoprene units (C_5) present in the parent molecule.

- **Stereochemistry:** Most terpenoids are optically active. Because of their unsaturation (double bonds) and functional groups, they frequently exist as different structural isomers or stereoisomers.

Subclasses and Visual Identification

The various subclasses of terpenoids are organized according to their ring systems and isoprene count, as detailed in the structural diagrams (Figures. 2.4). These figures illustrate how the basic isoprene backbone can be transformed into thousands of unique compounds.

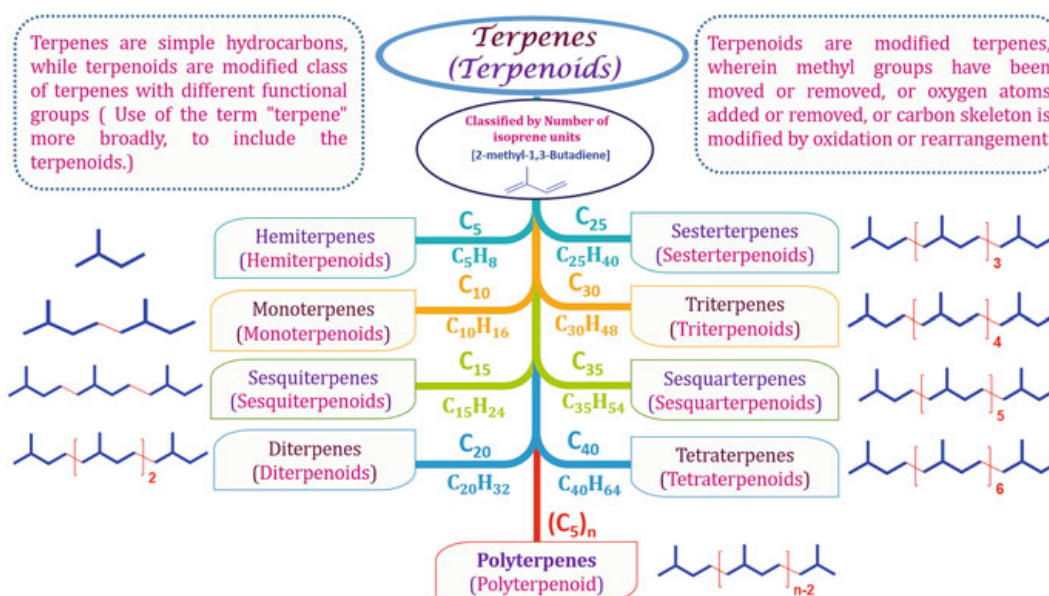


Figure 2.4 The different classes of terpene/terpenoid plant secondary metabolites on the basis of isoprene units and their common structural features based upon the number of carbon atoms

2.4.1. Hemiterpenoids

are the simplest class of terpenoids, consisting of a single isoprene unit (C_5). While they are small, they are fundamentally important as the basic structural units for all higher isoprenoids and for the production of various polymers.

a) Characteristics and Building Blocks

Hemiterpenoids are the simplest class of terpenoids, consisting of a single isoprene unit (C_5). While they are small, they are fundamentally important as the basic structural units for all higher isoprenoids and for the production of various polymers.

b) Key Examples

Beyond isoprene itself, other common hemiterpenoids found in plants include:

- **Isoprene:** The fundamental building block.
- **Isoamyl alcohol:** A common fermentation and plant-derived alcohol.
- **Organic Acids:** Specific hemiterpenoid acids like Angelic, Isovaleric, Senecioic, and Tiglic acids, which are often found as part of more complex molecules.

2.4.2. Monoterpenoids (C-10)

Definition : Origin of Monoterpenoids (C-10)

Monoterpenoids (C-10) are naturally occurring compounds composed of two isoprene units. They are derived from monoterpenes through the rearrangement or modification of their carbon skeleton.

a) Industrial Importance and Sources

Because of their pleasant odor, monoterpenoids are the primary constituents of essential oils. They are widely extracted from the leaves, bark, and roots of plants for use in the perfumery industry.

b) Structural Subdivisions

Based on their skeletal arrangement, monoterpenoids are categorized into three main structural types :

Acyclic (Open-chain): Examples include citral, geraniol, lavandulol, linalool, and myrcene.

Monocyclic (One ring): Examples include carvone, eucalyptol, limonene, menthol, α -terpineol, perillaldehyde, and thymol. **Bicyclic**

(Two rings): Examples include carene, sabinene, camphene, thujene, camphor, borneol, eucalyptol, and ascaridole.

2.4.3. Sesquiterpenoids (C-15)

Definition : Definition and Physical Properties

Sesquiterpenoids consist of three isoprene units. They are generally derived from parent sesquiterpenes through skeletal rearrangement and modification. In terms of physical properties, they form the higher boiling fraction of essential oils (meaning they are less volatile than monoterpenoids)

a) Structural Classification

Similar to monoterpenoids, this class exists in several structural forms:

- **Acyclic:** Examples include farnesol and β -nerolidol.
- **Monocyclic:** Examples include β -bisabolene, α -zingiberene, and α -humulene.
- **Bicyclic:** Examples include β -santalol, β -caryophyllene, and δ -cadinene.
- **Tricyclic:** Examples include khushimol, thujopsene, and patchoulol

b) Sesquiterpene Lactones

This is a chemically distinct subclass of sesquiterpenoids. Their defining feature is the presence of a δ -lactone system. Key Examples: Artemisinin, alantolactone, costunolide, and thapsigargin.

2.4.4. Diterpenoids (C₂₀)

Definition : Composition

Diterpenoids are widely distributed throughout the plant kingdom. They are composed of four isoprene units (20 carbon atoms). Their structures are formed when the parent diterpene skeleton is rearranged or modified by transferring or replacing one or more atoms.

a) Chemical State

These compounds commonly exist in a polyoxygenated form. This means they often feature keto and hydroxyl groups that have been esterified by small aliphatic or aromatic acids.

b) Structural Classification

Diterpenoids are categorized based on their skeletal core into the following groups:

- **Acyclic:** Examples include phytol and retinol.
- **Bicyclic:** Example: 9-geranyl- α -terpineol.
- **Tricyclic:** Examples include sclareol, marrubiin, and salvinorin A.
- **Tetracyclic:** Examples include abietic acid, carnosic acid, and tanshinone I.
- **Pentacyclic:** Examples include gibberellin A1 and steviol.
- **Macrocyclic:** A notable example is taxol.

2.4.5. Sesterterpenoids (C₂₅)

Definition : Definition and Rarity

Sesterterpenoids are a rare class of terpenes. They are comprised of five isoprene units, resulting in a backbone of 25 carbon atoms. They are formed through the rearrangement or amendment of the original sesterterpene skeleton.

a) Natural Sources

Natural Sources Unlike other terpenoids, this subclass is rarely found in higher plants. Their most common sources include:

- **Fungi**
- **Bacteria**
- **Marine sponges**

b) Structural Frameworks

Despite their rarity, they exhibit a variety of structural frameworks:

- **Linear:** Example: hippolide E.
- **Monocyclic:** Example: manoalide.
- **Bicyclic:** Example: leucosceptrine.
- **Tricyclic:** Example: heliocide H1.
- **Tetracyclic:** Example: sesterstatin 7.
- **Macrocyclic:** Example: nitinol.

2.4.6. Triterpenoids (C₃₀)

Definition : Definition and Origin

Triterpenoids are a large and important group of natural products composed of six isoprene units. They are formed as modified and rearranged derivatives of triterpenes, typically featuring oxygen-containing functional groups.

a) Biosynthesis

The vast diversity of triterpenoid skeletons is derived from C₃₀ precursors, specifically squalene or oxidosqualene. The final structure depends on the different "ring closure" pathways these precursors undergo during synthesis.

b) Structural Complexity

These compounds possess relatively complex cyclic skeletons that often include alcohol, aldehyde, or carboxylic acid groups. Most Abundant Types:

Tetracyclic (4 rings) and **Pentacyclic** (5 rings) structures. Other Forms: Acyclic, monocyclic, dicyclic, tricyclic, and hexacyclic forms also exist in nature

c) Key Examples

Many well-known bioactive compounds belong to this class:

Pentacyclic triterpenes: α -amyrin, β -amyrin, ursolic acid, oleanolic acid, and betulinic acid.

Phytosterols: sitosterol, stigmasterol, campesterol, and α -spinasterol.

Others: cucurbitacin B, asiatic acid, and celastrol.

2.4.7. Sesquiterpenoids

Sesquiterpenoids consist of seven isoprene units and are a rare group of terpenoids typically found in microbial origin.

2.4.8. Tetraterpenoids (C₄₀)

Definition and Composition

Tetraterpenoids are compounds composed of eight isoprene units, forming a C₄₀ skeleton.

They are chemically modified derivatives of parent tetraterpenes, often containing oxygen-containing functional groups due to skeletal rearrangement or modification

a) Biological Function

Pigmentation This class is most famous for producing the distinct pigmentation seen in the plant kingdom. They are responsible for the red, yellow, and orange colors found especially in flowers and fruits.

b) Role in Photosynthesis

Beyond color, tetraterpenoids (specifically many carotenoids) are essential for plant life. They act as accessory pigments in photosynthesis, helping the plant capture light energy more efficiently.

2.4.9. Polyterpenoids (C_n)

Definition : Definition and Composition

Polyterpenoids are polymeric hydrocarbons consisting of more than eight isoprene units. Unlike the previous classes, which have a fixed number of units, these are long-chain polymers.

a) Isomeric Configurations

The properties of these compounds depend heavily on the spatial arrangement (configuration) of the isoprene units.

They exist in two primary forms:

- **Cis-configuration:** This produces natural rubber, which is highly elastic.
- **Trans-configuration:** This produces materials such as gutta-percha and balata rubber, which are generally tougher and less elastic than natural rubber.

2.4.10. Terpenes and Terpenoids: Applications

a) Industrial Application Solvents and Bio-fuels

Example

Limonene (a monoterpene) is used industrially as a biodegradable, "green" solvent to replace toxic petroleum-based chemicals in cleaning products and degreasers. Additionally, Turpentine (derived from pinene) is a vital raw material in the manufacturing of resins, paints, and varnishes

b) Medical Application : Drug Delivery and Penetration Enhancers

Example

Menthol and other terpenes are used as "penetration enhancers" in transdermal medical patches. They temporarily alter the skin barrier, allowing medication (like nicotine or hormone treatments) to be absorbed into the bloodstream more effectively.

c) Pharmaceutical Application: Anti-Malarial and Anti-Cancer Drugs

Example

Artemisinin (a sesquiterpene lactone) is the gold-standard pharmaceutical treatment for malaria worldwide. Another critical example is Paclitaxel (Taxol), a complex diterpenoid used as a powerful chemotherapy agent to treat breast, ovarian, and lung cancers by inhibiting cell division.

d) Food Application: Natural Flavors and Colorants

Example

Carotenoids (tetraterpenoids like β -carotene and lycopene) are used extensively as natural food dyes to provide yellow, orange, and red colors to products like margarine and juices. Furthermore, Citral and Geraniol are used as flavoring agents to provide citrus and floral notes in confectioneries and beverages.

2.5. Sulfur-Containing Compounds

Sulfur-containing compounds is another important class of small group of low-molecular-weight plant secondary metabolites (PSMs). Sulfur-containing PSMs often have a characteristic smell and play various role such as signaling molecules (for fundamental cellular functions) as well the defense compounds against herbivores and pathogenic organism. The structural diversity in sulfur PSMs such as different sulfur bonds is the main and an important feature together with other structural characteristics responsible for their interesting biological activities with medicinal effect and therapeutic significance. The sulfur-containing PSMs are subdivide into different subclasses (Figure 2.5)

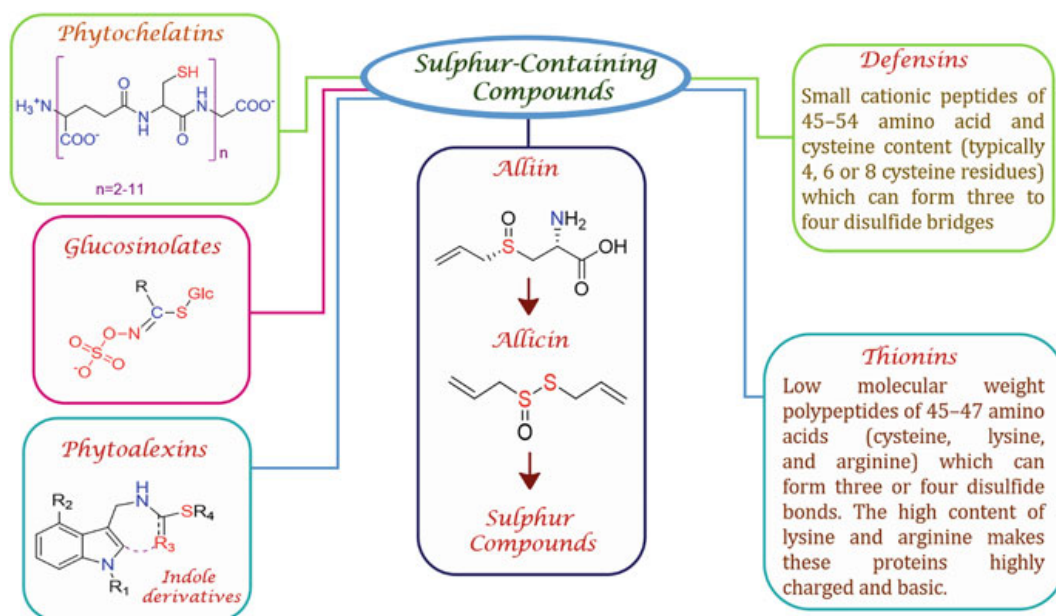


Figure 2.5 The different classes of sulfur-containing plant secondary metabolites and their common structural features

2.5.1. Phytochelatins

Definition and Structure

Phytochelatins are ubiquitous, sulfur-containing small peptides found in plants. They are considered oligomers of glutathione and possess a universal chemical structure: $(\delta\text{-glutamyl-cysteine})_n\text{-glycine}$, where n ranges from 2 to 11.

a) Biological Function

Heavy Metal Management: Phytochelatins play a vital role in managing heavy metals within the plant. They act through a metal chelation reaction, effectively sequestering (capturing) heavy metal ions.

i Detoxification and Protection

As heavy metal hyperaccumulators, these peptides provide a defense mechanism by: Preventing heavy metals from binding to the sulfhydryl groups of essential enzymes and proteins.

2.5.2. Glucosinolates

Chemical Nature **Glucosinolates** are a diverse class of plant secondary metabolites (PSMs) characterized by containing both sulfur and nitrogen.

a) Core Structure

Their core chemical structure consists of : A β -D-thioglucose group. An N-hydroximosulfate ester. A variable side chain (which can be aliphatic, aromatic, or indolic) derived from an amino acid.

b) Enzymatic Hydrolysis

When the plant is damaged, enzymatic hydrolysis of the thioglucose group occurs, converting these compounds into biologically active isothiocyanates.

/ Glucosinolate/ Resulting Isothiocyanate/ $\rightarrow\rightarrow\rightarrow\rightarrow\rightarrow\rightarrow$ /Allylglucosinolate (**Sinigrin**)/.

2.5.3. Phytoalexins

Definition and Chemical Nature

Phytoalexins are a diverse and important class of compounds that include alkaloids, phenolics, and sulfur-containing compounds. They are defined as low-molecular-weight antibiotics.

a) Inducible Defense Mechanism

Unlike "pre-formed" metabolites, phytoalexins are inducible PSMs. This means:

- They are produced specifically in response to pathogen attacks or environmental stresses.
- They are secreted and accumulated temporarily by plants to manage biotic and abiotic stresses.

b) Sulfur-Containing Phytoalexins

Some phytoalexins are characterized by containing at least one sulfur atom in their side chain or ring structure.

Key Examples: Camalexins, brassinin, brassitin, brassicanal A and B, spirobrassinin, rutalexin, wasalexin A, and rapalexin A and B.

2.5.4. Defensins

Definition and Biological Function

Defensins are a class of cationic antimicrobial peptides. They serve as a primary line of defense for the plant by exhibiting two main types of activity: Direct Antimicrobial Activity: They actively kill or inhibit the growth of pathogens. Immune Signaling: They help coordinate the plant's broader immune response.

a) Chemical Structure

These molecules are characterized as cysteine-rich proteins. Their physical framework is defined by: A fold that is rich in β -sheets. A framework of six cysteines that are connected via disulfide links.

b) Classification

Defensins are generally categorized into three distinct types based on the specific disulfide pairing (the pattern of connections) between their cysteine residues: α -defensins, β -defensins, θ -defensins.

2.5.5. Sulfur-Containing Compounds: Applications

a) Industrial Application: Bio-fumigants and Agricultural Pesticides

Example

Isothiocyanates (derived from glucosinolates found in mustard and rapeseed) are used in "bio-fumigation." When plant tissues are incorporated into the soil, these sulfur compounds are released to naturally suppress soil-borne pathogens, fungi, and nematodes, reducing the need for synthetic chemical pesticides.

b) Medical Application: Bioremediation and Heavy Metal Detection

Example

Phytochelatins are used in medical and environmental research as biomarkers for heavy metal toxicity. Because they bind specifically to toxic metals like cadmium and lead, they are utilized in developing biosensors to detect high metal levels in biological samples or contaminated water sources.

c) Pharmaceutical Application: Chemopreventive and Anti-tumor Agents

Example

Sulforaphane (produced from the glucosinolate glucoraphanin found in broccoli) is widely studied and used in pharmaceutical supplements for its chemopreventive properties. It helps trigger phase II detoxification enzymes in the human body, which can protect cells from DNA damage and inhibit the growth of certain cancer cells.

d) Food Application: Pungent Flavoring Agents and Preservatives

Example

Allyl isothiocyanate (the main component of mustard oil and horseradish) is used in the food industry to provide the characteristic "sharp" or "hot" flavor in condiments. Additionally, its antimicrobial properties help in food preservation by inhibiting the growth of food-borne spoilage bacteria and molds

* *

*

End chapter questions

- Explain why many secondary metabolites, such as alkaloids or glucosinolates, are often toxic or bitter-tasting. How does this serve the evolutionary interest of the plant?
- Compare the chemical structures of Terpenoids (C_{30} or C_{40}) with Polyterpenoids (C_n). How does the difference in their chain length and configuration (cis vs. trans) determine their final industrial use?
- Phytoalexins are described as "inducible" metabolites. Explain the physiological advantage for a plant to produce these compounds only after a pathogen attack rather than maintaining high levels at all times.

- Industrial Green Chemistry: Limonene is frequently used as a "green solvent." Discuss the environmental benefits of using plant-derived terpenes in industrial cleaning compared to traditional petroleum-based solvents.
- Many life-saving drugs like Paclitaxel (Taxol) or Artemisinin come from secondary metabolites. What are the challenges of relying on wild plant harvesting for these drugs, and what alternative production methods exist?
- Glucosinolates are converted into isothiocyanates (like sulforaphane) when we chew certain vegetables. Describe the health benefits of this chemical reaction and why "active" enzymes are necessary for this process.
- Based on your knowledge of Phytochelatins, explain how plants can be used in "bioremediation" to clean up soil contaminated with heavy metals like lead or cadmium.
- In the food industry, why is it often more effective to use a mix of phenolic compounds (like those found in rosemary) rather than a single synthetic antioxidant to preserve oily foods?
- Nitrogen is a limiting nutrient for many plants. Why would a plant "invest" precious nitrogen into producing complex alkaloids like morphine or caffeine instead of using it for primary growth (proteins/DNA)?
- In the case of Defensins, how does the specific "disulfide-linked" framework contribute to the stability and effectiveness of these proteins in harsh external environments?

Industrial use of plants: biological basis for plant consumption.

III

By the end of Chapter 02

the learner will be able to explain and analyze the market-based classification of plant-derived by-products, based on their origin, nature, and main industrial valorization pathways.

1. Introduction

Many plant species are cultivated worldwide for industrial purposes, due to the wide range of natural substances they provide and their long-standing importance in various economic sectors. For example, flax (*Linum usitatissimum*) and hemp (*Cannabis sativa*) were historically linked to the production of canvas and textiles, as their fibers possess high mechanical strength and durability. Dye plants, such as indigo (*Indigofera tinctoria*) and madder (*Rubia tinctorum*), were essential to the textile finishing industry, supplying natural colorants used in fabric dyeing and treatment processes. Similarly, hops (*Humulus lupulus*) play a key role in the brewing industry, contributing characteristic bitterness, aroma, and preservation properties to beer.

The conversion of plant materials into commercial products often involves costly and labor-intensive processing operations. Depending on the intended application, different plant parts—roots, stems, leaves, flowers, and seeds—are exploited. These transformations lead to the production of a wide variety of industrial goods, including vegetable oils (e.g., sunflower *Helianthus annuus*, olive *Olea europaea*), fibers, natural dyes, tannins (e.g., oak *Quercus* spp.), essential oils, resins, and other valuable plant-derived substances.

The use of plant resources in bioindustries is therefore multiple and diverse, encompassing sectors such as textiles, food and beverages, cosmetics, pharmaceuticals, leather processing, and materials manufacturing. Today, increasing attention is given to the valorization of plant biomass and by-products, reflecting the growing importance of renewable resources and sustainable industrial practices. As a result, plant-derived natural substances continue to play a central role in modern bioindustries.

2. Industrial Classification of Plants

Definition

In industrial terminology, industrial crops refer to all cultivated plants that are intended to be processed by industry for human consumption, animal feed, or various non-food applications. These crops are not consumed directly in their raw form but undergo one or more industrial transformation processes to obtain marketable products.

Industrial crops are characterized by a high production potential, both in terms of yield and quality, and they contribute significantly to the optimal valorization of agricultural land. Their cultivation is generally oriented toward maximizing biomass production or the accumulation of specific plant-derived substances of industrial interest.

Most industrial crops are row crops, often described as cleaning crops, because they require regular soil cultivation and weed control. As a result, they are highly mechanized cropping systems, involving successive operations such as sowing → inter-row cultivation → hoeing → crop treatments → harvesting. This intensive management contributes to improved field hygiene and enhanced crop performance.

Due to their economic value and technological requirements, industrial crops occupy a strategic position in bioindustries, supplying raw materials for sectors such as food processing, textiles, pharmaceuticals, cosmetics, energy, and materials manufacturing.

The most important classes

Industrial crops are grouped according to their uses into several groups.

2.1. Oilseed Crops

Oilseed crops are industrial plants cultivated primarily for oil production, with oils extracted mainly from their seeds or fruits. These vegetable oils represent an essential group of plant-derived natural substances, widely used in both food and non-food industries.

From a nutritional perspective, oilseed crops provide edible oils rich in fatty acids, which are fundamental to human and animal diets. Industrially, these oils serve as raw materials in the manufacture of cosmetics, soaps, detergents, lubricants, paints, varnishes, and bio-based materials. In addition, oilseed by-products, such as oilcakes and meals, are commonly used as high-protein animal feed.

Among the most important oilseed crops are sunflower (*Helianthus annuus*), soybean (*Glycine max* (L.) Merr.), safflower (*Carthamus tinctorius*), groundnut or peanut (*Arachis hypogaea*), and rapeseed (*Brassica napus* var. *oleifera*). These species are characterized by high oil yields, adaptability to different agro-climatic conditions, and strong economic relevance.

Due to their high productivity and their role in agricultural systems, oilseed crops contribute significantly to the valorization of agricultural land and to the supply of renewable raw materials for bioindustries. Their strategic importance continues to grow in response to increasing demand for plant-based oils and sustainable industrial resources.

Main Crops

The major oil seed crops are listed below :

2.1.1. Soybean Seed

The seeds are rich in protein, mainly globulins, which make up 90% of the total proteins and 36% of the seed weight. Ten percent of the seed weight is carbohydrate, mainly sugars, and 3% is starch. The seed is relatively low in oil compared with other oilseed crops at $\approx 20\%$. Following oil extraction, heat treatment is used to inactivate enzymes in the high-protein meal that otherwise reduce the digestibility of the stock feed.

Traditional soybean oil is polyunsaturated with 48–59% linoleic acid (C18:2) and 4–11% linolenic acid (C18:3) (Table 3.1).

Breeding has produced cultivars with various fatty acid profiles; in particular, high-oleic acid soybean oil, which contains up to 84% oleic, has less saturated (palmitic) acid and is more stable for cooking purposes. The meal may also be used for industrial purposes such as cosmetics, paints, and adhesives and various edible purposes.

2.1.2. Cottonseed

Cotton is basically grown for its fiber, but the seed has several important components consisting of oil (16%), protein (37%), hull (37%), and linters (10%). Also, within the kernel is a phenolic compound called gossypol, $\approx 1\%$ of the seed weight: toxic to humans and monogastric animals. Cottonseed oil, prior to refining, is red due to the residual gossypol and associated products. Increased seed oil content has been a secondary objective to fiber production although the value of the oil is significant. Cottonseed oil contains 47–58% linoleic acid.

2.1.3. Groundnut or Peanut

Peanuts are a valuable source of oil and also produce a high protein meal for stock feed. Increased yields are an important breeding priority, particularly in developing countries where yield is poor. Increased oil content is also desirable as peanuts have a wide range from 40% to $>60\%$ in wild types. Reduction in linoleic acid produces oil with a better oxidative stability. Meal protein is high at $\approx 46\%$, but the amino acid profile is lacking in sulfur-containing amino acids particularly methionine. The components of whole peanuts are protein (26%), oil (41%), and carbohydrates (24%). The main product is the oil that has $\approx 80\%$ unsaturated fatty acids making it a nutritionally favorable oil. Additionally, the level of oleic acid and palmitic acid makes it stable with good keeping qualities for cooking and in food mixtures.

2.1.4. Rapeseed

Traditional rapeseed oil characteristically contains high levels of erucic acid, found to have detrimental effects on the myocardial muscle of rats fed the oil. The value of the meal was also low due to the presence of sulfur-containing compounds called glucosinolates, found to have deleterious effects on the thyroid gland of monogastric animals.

The development of cultivars with very low levels of glucosinolate in the meal has also been achieved. new terms have been used to discriminate

between the types. **Canola** is recognized under ISO 5725, Codex Alimentarius, and ISTA as cultivars of rapeseed with $<2\%$ erucic acid in the oil and <30 mmol of aliphatic glucosinolates in the meal.

The seed oil is the main value of the crop yielding 42% oil, while the meal contains 35% protein. Current canola cultivars have very low erucic acid and saturated fatty acid levels and a good proportion of oleic (C18:1), linoleic (C18:2), and α -3 linolenic (C18:3) fatty acids. Alternatively, high-erucic acid oil is utilized for industrial purposes such as cutting oils. Erucic acid is extracted from high-erucic acid rapeseed and converted to erucamide for plastic manufacture.

2.1.5. Sunflower

Sunflower is grown for the seed oil, which is $\approx 80\%$ of the seed value. The dehulled meal has 28–42% protein. The oil is highly considered due to its low linolenic acid value and therefore oxidative stability for cooking, salad oil, and margarines. Heritability of high oil is reliable, and it has been possible to increase oil contents from 30% in early types to over 50% in recent years. Sunflower cultivars with a range of fatty acid profiles have been developed including high oleic acid (75–91%) with reduced levels of linoleic acid (2–17%) and high levels of α -tocopherol (vitamin E), providing the market with very stable monounsaturated oil for cooking purposes.

2.1.6. Sesame Seed

Sesame seeds are used intact or as oil and meal. The seeds generally have high oil content of $\approx 50\%$ and $\approx 25\%$ protein, although the oil content can vary between 40% and 60%. The fatty acid composition also shows a large range (Table 3.1).

A high oleic acid (40%) and linoleic acid (45%) content makes the oil nutritionally beneficial. The unsaponifiable fraction of the oil contains sesamin and sesamol that during the refining process form sesamol and sesaminol. These are strong antioxidants that give the oil exceptional resistance to oxidation and rancidity.

2.1.7. Linseed

Due to its high iodine value, linseed oil has been used primarily for industrial purposes, such as linoleum floor covering, with a high level of unsaturated fatty acids making the oil very reactive and resulting in a short shelf life. Low linolenic acid cultivars have introduced linseed to the edible food market. In

1994, the Flax Council of Canada developed the term 'solin' to describe linseed with $<5\%$ linolenic acid. The original hybridization work was carried out by the CSIRO in Australia with the release of two Linola cultivars in 1992 under the Plant Variety Rights scheme.

Linola™ 989 has been reported as 46% oil (dry basis) and 34% protein. Linseed meal has a high crude protein value but low lysine levels. It also has a high level of soluble fiber, called mucilage, that is indigestible to nonruminants and reduces the energy value of the meal.

2.1.8. Mustard Seed

Typically, mustard oil is high in erucic acid (20–50%) and the meal is high in glucosinolate compounds (50–150 mM /g), providing pungency to mustard for condiments but reducing the palatability of the meal for stock feed. With plant breeding, very low levels of erucic acid have been achieved, and current aims are to develop cultivars that are more closely related to LEAR cultivars, with increased oleic acid content.

2.1.9. Safflower

Safflower was originally domesticated for its flowers: red carthamin dye was extracted for coloring food and cloth. Early cultivars were unsuitable for commercial development due to low oil content of $\approx 30\%$. Breeding programs have since increased oil contents and altered the fatty acid profiles to take it from an industrial product to the edible oil market with modern cultivars containing 34% or more oil. Traditional high linoleic acid types contain $\approx 68\text{--}83\%$ linoleic acid and 8–22% oleic acid (Table 3.1). Through plant breeding, high oleic acid levels (70–84%) have been achieved.

Table 3.1 Fatty acids composition and nature of main Oil seed Crops

Fatty acid	Name	Palmitic	Palmitoleic	Stearic	Oleic	Linoleic	Linolenic	Arachidic	Gadoleic	Behenic	Erucic
	Symbol	C16:0	C16:1	C18:0	C18:1	C18:2	C18:3	C20:0	C20:1	C22:0	C22:1
Oilseed	Type										
Soybean	Normal	8–14	<0.2	2–6	17–30	48–59	4–11	<0.6	<0.5	<0.7	<0.3
Soybean	High oleic acid	6		3	84	2	4				
Cottonseed	Normal	21–26	<1.2	2–3	15–22	47–58	<0.5	0.2–0.5	<0.1	<0.6	<0.3
Peanuts	Normal	8.3		3.1	56	26		2			
Rapeseed	Low erucic acid	2–7	<0.6	1–3	51–70	15–30	5–14	0.2–1.5	0.1–5	<0.6	<2.0
	High erucic acid	1.5–6	<3	0.5–3	8–60	11–23	5–13	<3	3–15	<2	2–60
	High oleic acid	3–4		2–3	63–76	13–25	2–3		1–2	<0.6	<0.2
Sunflower	Linoleic acid	5–8	<0.3	2–7	14–40	48–74	<0.3	0.1–0.5	<0.3	0.3–1.5	<0.3
	Mid-oleic acid	4–5		3–4	50–75	20–30	<1				
	Oleic acid	2–5	<0.1	3–7	75–91	2–17	<0.3	0.2–0.5	0.1–0.5	0.5–1.5	<0.3
Sesame seed	Normal	8–12	<0.2	5–6	36–42	42–48	0.3–0.4	0.3–0.6	<0.3	<0.3	
Linseed	Normal	5–7	<0.3	3–4	19–20	14–17	52–61	<0.5	<0.6		
	Low linolenic acid	6		3–4	15	73	2–3				
Safflower	Linoleic acid	5–8	<0.2	2–3	8–22	68–83	<0.1	0.2–0.4	<0.3	<1.0	<1.8
	Oleic acid	3–6	<0.2	1–3	70–84	9–20	<1	0.3–0.6	<0.5	<0.4	<0.3
Mustard seed	<i>B. carinata</i>	4–10		<2	8–23	15–22	18–27		<2		20–50
	<i>B. nigra</i>	2–7		<2	10–27	15–22	11–27				33–45
	<i>B. juncea</i>	3–10		1–3	15–64	14–28	9–24		1–3		<40

2.2. Sugar Crops

Sugar crops are plants cultivated specifically for the production of sugar. They are an essential source of sweeteners for human consumption and for various industrial applications.

Typical examples include sugar beet (*Beta vulgaris*), sorghum (*Sorghum vulgare*), and sugarcane (*Saccharum officinarum* L.). These crops are characterized by their high sucrose content, making them suitable for both food processing and industrial uses such as bioethanol production, fermentation, and other sugar-derived products.

2.2.1. Sugar beets

Sugar beets (*B. vulgaris* L. ssp. *vulgaris*) are members of the family Amaranthaceae (formerly Chenopodiaceae) and order Caryophyllales which have a C3 photosynthetic system. Cultivated beets are included in the subspecies *vulgaris* and include leafy beets (chard), garden beets (red), fodder beets (forage), and sugar beets.

Leafy beets have been grown since pre-Roman times, however sugar beets were relatively recently domesticated in the late 18th century, and breeding has led to cultivated beets with a biennial reproductive schedule, flowering only after overwintered vernalization (Biancardi et al., 2010). Sugar beets grown in the northern hemisphere are typically planted in the early spring with harvesting 5–9 months later depending on soil and environmental conditions. In warmer or Mediterranean climates, “winter beets” can be planted in the

autumn and allow harvest through the following spring, summer, or fall. Where successful sugar beet industries have developed, diverse adjustments to the physiological limits to crop growth have been made, resulting in a large number of different cropping patterns worldwide.

2.2.2. sweet sorghum

Belonging to the family Poaceae, sweet sorghum was originated in East Africa and widespread in other regions such as South Africa, Europa, Australia, and the United States. This plant stands out from other crops due to its high adaptability to adverse environmental conditions, such as drought resistance, high heat, and different soil types. Hence, it is adapted to subtropical and temperate regions, being specially indicated for regions with water restrictions. It is a crop with short a life cycle, varying between 120 and 130 days, presents low implementation costs, low water requirements, and seed propagation.

2.2.3. Sugarcane

Sugarcane (*Saccharum officinarum* L.) is the most widespread crop grown for sugar production. Therefore knowledge of the environmental circumstances that determine their stress is important to improve the production of sucrose and ethanol, two products of primary interest in the food and fuel industries. The currently cultivated commercial varieties are complex hybrids of two or more species. This is the case of *S. officinarum* and *S. spontaneum*, for which the hybrid formed maintains the efficient level of productivity of the first species and the high resistance to diseases of the second.

Sucrose in *S. officinarum* is synthesized and accumulated in the parenchymatous cells of the stems, although some soluble polysaccharides may be transiently produced . This is accomplished by a decrease in the yield of sucrose production and a product whose appearance and properties produce rejection from the consumer is obtained.

2.3. Starch (Amylaceous) Crops

Starch crops are plants specifically cultivated for the production of starch, a versatile carbohydrate widely used in both food and non-food industries. Starch serves as a thickening, gelling, or stabilizing agent in foods, and as a raw material in industries such as paper, textiles, adhesives, biodegradable plastics, and bioethanol production.

The most common starch crop is maize (corn) (*Zea mays* L.), which provides large quantities of easily extractable starch from its grains. Other important starch-producing plants include potato (*Solanum tuberosum*), cassava (*Manihot esculenta*), and wheat (*Triticum aestivum*), which are exploited for their high starch content in tubers, roots, or seeds.

The industrial processing of these crops typically involves cleaning, milling, extraction, and refinement, transforming plant biomass into pure starch and related co-products such as glucose syrups, maltodextrins, and starch derivatives. These co-products are widely used in food processing, pharmaceuticals, cosmetics, and material industries, highlighting the economic and industrial importance of starch crops.

Starch crops are thus strategically valuable due to their high yield, versatility, and wide industrial applications, forming a cornerstone of many bioindustrial systems worldwide.

2.4. Textile Crops

Textile crops are plants cultivated primarily for the production of fibers used in the textile industry. These fibers are extracted from seeds, stems, or leaves and form the raw material for yarns, fabrics, and other textile products.

Typical examples include cotton (*Gossypium hirsutum* and *Gossypium barbadense*), valued for its soft and strong seed fibers, and flax (*Linum usitatissimum*), which provides long, durable fibers from the stem for linen production. These crops are cultivated with attention to fiber quality, length, and strength, which are critical parameters for textile manufacturing.

The industrial processing of textile crops involves harvesting, fiber separation, cleaning, spinning, and weaving or knitting, converting plant biomass into finished textile materials. Cotton and flax fibers are also used in composite materials, paper, and industrial textiles, demonstrating their versatility beyond clothing.

Textile crops are therefore strategically important in both traditional and modern industries, contributing to economic development, employment, and technological innovation in the textile sector.

2.5. Stimulant Crops

Stimulant crops are plants cultivated for the production of bioactive compounds that have physiological stimulating effects on humans. These crops are widely used in the food and beverage industries, as well as in some pharmaceutical and recreational applications.

Typical examples include tobacco (*Nicotiana tabacum*), primarily grown for its nicotine content, which is used in the manufacture of cigarettes, cigars, and other tobacco products; tea (*Camellia sinensis*), valued for its caffeine and polyphenols, widely consumed as a brewed beverage; and coffee (*Coffea arabica*), whose beans are rich in caffeine and flavor compounds, forming one of the most popular beverages globally.

The industrial processing of stimulant crops involves harvesting, drying, fermentation (in the case of tea and coffee), roasting (for coffee), and packaging, transforming raw plant materials into finished commercial products. These crops are of high economic importance, generating significant revenue in both domestic and international markets.

Stimulant crops thus represent a strategically valuable group of plants due to their unique chemical compounds, widespread consumption, and strong industrial demand.

2.6. Industrial Vegetables

Definition

Industrial vegetables are plants cultivated on a large scale for processing into food products rather than for fresh consumption. They are selected for their high yield, uniformity, and suitability for industrial transformation, which makes them ideal raw materials for canning, freezing, drying, or making sauces, pastes, and other processed foods.

Example

Typical examples include tomato (*Lycopersicon esculentum*), widely used in tomato paste, sauces, and ketchup production; field pea (*Pisum arvense*) and common bean (*Phaseolus vulgaris*), often processed into canned or frozen legumes; and pepper (*Capsicum annuum*), used for spices, sauces, and pastes. Other vegetables, such as carrots, onions, and cabbage, are also grown for industrial processing.

Industrial vegetable cultivation emphasizes mechanized farming, pest and disease control, and post-harvest handling to maintain product quality and processing efficiency. These crops are crucial for the food processing industry, providing convenient, safe, and long-lasting products for consumers worldwide.

2.7. Condiment Crops

Definition

Condiment crops include plants cultivated for the production of herbs and spices used to enhance the flavor, aroma, and sensory qualities of food. These crops are valued for their essential oils, oleoresins, and other aromatic compounds, which are responsible for their characteristic taste and fragrance.

Example

Typical examples of condiment crops are black pepper (*Piper nigrum*), one of the most widely traded spices in the world, cumin (*Cuminum cyminum*), and caraway (*Carum carvi*). These plants are mainly exploited for their seeds or fruits, which are harvested, dried, and processed before being marketed as whole spices or ground products.

Beyond culinary uses, condiment crops also find applications in the food processing industry, pharmaceutical formulations, and cosmetics, due to their preservative, antioxidant, and aromatic properties. Their cultivation and processing require careful control of harvest timing, drying conditions, and storage, as these factors strongly influence quality and commercial value.

Condiment crops therefore represent an important category of industrial plants, combining high economic value, global demand, and a wide range of traditional and modern applications.

2.8. Aromatic or Perfume Plants

Definition

Aromatic or perfume plants are cultivated primarily for the production of essential oils and fragrant compounds used in perfumes, cosmetics, and flavoring industries. These plants are valued for their volatile aromatic compounds, which are extracted through distillation, solvent extraction, or cold pressing.

Example

Typical examples include lavender (*Lavandula angustifolia*), widely grown for its calming-scented essential oil used in perfumery, aromatherapy, and personal care products; jasmine (*Jasminum officinale*), valued for its intensely fragrant flowers used in high-quality perfumes; and eucalyptus (*Eucalyptus globulus*), cultivated for its eucalyptus oil, which has fragrant, medicinal, and industrial applications.

The cultivation and processing of perfume plants require careful harvesting and post-harvest handling, as the quality and yield of essential oils strongly depend on factors such as plant maturity, time of harvest, and extraction methods. Aromatic plants thus represent an important category of industrial crops, combining economic value, global demand, and versatility in multiple sectors, including cosmetics, pharmaceuticals, and household products.

2.9. Crops for Alcohol Production

Definition

Alcohol-producing crops are plants cultivated for the industrial conversion of their sugars into alcohol, which can be used in food, beverages, and biofuel industries. This group of crops represents a major sector of plant-based bioindustries, providing raw materials for wine, spirits, beer, and bioethanol.

Example

Typical examples include:

- Grapevine (*Vitis vinifera*), used for wine production,
- Apple (*Malus domestica*), used for cider and fruit brandies,
- Barley (*Hordeum vulgare*) and wheat (*Triticum durum*), key cereals for beer and spirits,
- Sugarcane (*Saccharum officinarum* L.) and maize (corn) (*Zea mays* L.), widely used for industrial ethanol production,
- Cherry (*Prunus cerasus*), used for fruit brandies and liqueurs.

These crops are processed through fermentation of sugars by yeast or other microorganisms, yielding ethanol. The resulting ethanol can serve multiple purposes:

- Food and beverage applications — such as wine, beer, spirits, liqueurs, and culinary alcohol.
- Biofuel applications — ethanol is refined into bioethanol, a renewable fuel blended with gasoline, contributing to sustainable energy production and reduction of fossil fuel dependency.

Industrial processing requires careful selection of raw materials, sugar content optimization, and controlled fermentation conditions to ensure high ethanol yield and quality, whether for consumption or fuel. Alcohol-producing crops are therefore strategically important in modern bioindustries, combining economic value, technological innovation, and environmental relevance.

2.10. Medicinal and Aromatic Plants

Definition

Medicinal and aromatic plants are cultivated for their bioactive compounds that are used in pharmaceutical, nutraceutical, cosmetic, and food industries. These plants produce secondary metabolites such as alkaloids, flavonoids, essential oils, tannins, and phenolic compounds, which have therapeutic, aromatic, or preservative properties.

Example

Typical examples include:

- Chamomile (*Matricaria chamomilla*), valued for its anti-inflammatory and calming properties, used in teas, cosmetics, and herbal medicines.
- Peppermint (*Mentha × piperita*), widely cultivated for menthol-rich essential oils used in pharmaceuticals flavorings, and oral care products.
- Rosemary (*Rosmarinus officinalis*), providing antioxidant compounds and essential oils for food preservation, cosmetics, and aromatherapy.

- Ginseng (*Panax ginseng*), renowned for its stimulant and adaptogenic properties in nutraceuticals and herbal supplements.
- Echinacea (*Echinacea purpurea*), commonly used for its immune-boosting bioactive compounds in dietary supplements and herbal remedies.

The industrial processing of these plants involves harvesting, drying, extraction, distillation, and purification, depending on the target compound and intended use. Medicinal and aromatic plants are high-value crops, often requiring careful cultivation practices and quality control to ensure consistent bioactive content.

These crops play a strategic role in bioindustries, bridging traditional herbal medicine and modern pharmaceutical, cosmetic, and food applications, while also contributing to sustainable economic development in many agricultural regions.

3. Industrial Use of Plant-Derived Biomolecules

3.1. Agro-Food Industry

The agro-food industry encompasses all processes that transform plant-derived raw materials into food products, ranging from primary transformations to elaborate or value-added processing. This sector is one of the largest users of plant biomolecules and plays a crucial role in food supply, nutrition, and industrial applications.

Primary (Direct) Transformations

Primary transformations involve direct processing of plant raw materials to obtain basic products, often without chemical modification, but sometimes using enzymatic or fermentation processes.

Fermentation industry: Uses plant sugars or starches to produce alcoholic beverages.

Examples:

- Wine from grapes (*Vitis vinifera*)
- Beer from barley (*Hordeum vulgare*)
- Cider from apples (*Malus domestica*)

Sugar industry: Processing of sugarcane (*Saccharum officinarum*) or sugar beet (*Beta vulgaris*) to obtain sucrose, molasses, or syrups.

Oil extraction (trituration): Seeds from sunflower (*Helianthus annuus*), soybean (*Glycine max*), and rapeseed /canola (*Brassica napus*) are processed to obtain edible oils. These primary processes are foundational steps that provide the raw materials for more complex food production.

Elaborate (Value-Added) Transformations

Elaborate transformations involve further processing of plant products into finished or semi-finished food products, often combining ingredients, additives, or advanced technologies.

Food additives and texturants: Plant starch, pectin, and gums are used to modify texture, viscosity, and stability in products such as sauces, jams, and desserts.

Conservation and preservation: Plant-derived antioxidants (e.g., rosemary extract, tocopherols) help prolong shelf life of oils, baked goods, and snacks.

Processed foods:

- Chocolate (from cacao beans, *Theobroma cacao*)
- Pasta (from durum wheat, *Triticum durum*)
- Biscuits and pastries (wheat flour, sugar, plant oils, cocoa)
- Fruit preserves and jams (sugar, pectin, fruits)

These processes add value, improve sensory qualities, and extend the usability of plant-derived biomolecules, linking raw plant materials to consumer-ready products.

3.2. Pharmaceutical Industry

The pharmaceutical industry utilizes a wide range of plant-derived biomolecules, particularly secondary metabolites, which are formed from primary metabolites such as simple sugars, amino acids, and lipids. In plants, the exact role of many secondary metabolites is still poorly understood, but they contribute to defense, signaling, and adaptation.

Many of these metabolites possess pharmacological properties that are exploited for therapeutic purposes, either by:

Extraction and purification from the plant:

- Digoxin from foxglove (*Digitalis purpurea*), used to treat heart failure and arrhythmias.
- Morphine from opium poppy (*Papaver somniferum*), a powerful analgesic for severe pain.
- Quinine from cinchona bark (*Cinchona* spp.), historically used to treat malaria.
- Atropine from deadly nightshade (*Atropa belladonna*), used in ophthalmology and as an antispasmodic.

Direct use of the plant or simple preparations:

Plant powders, tinctures, teas, and extracts are often used in herbal medicine.

Examples:

Chamomile (*Matricaria chamomilla*) for mild anti-inflammatory and calming effects,

Peppermint (*Mentha × piperita*) for digestive relief, and

Echinacea (*Echinacea purpurea*) for immune support.

Complement

The industrial exploitation of plant secondary metabolites involves harvesting, drying, extraction, purification, and formulation to ensure consistent quality, potency, and safety. Some metabolites are further chemically modified or semi-synthesized to enhance efficacy or reduce toxicity.

Overall, the pharmaceutical industry demonstrates the strategic importance of plant-derived biomolecules, bridging traditional herbal practices and modern medicine, and providing valuable therapeutics for human health.

3.3. Chemical industry

3.3.1. Production of Surfactants

The transformation of plant-derived molecules allows the production of surfactants, which are molecules with diverse functional properties, including detergent, emulsifying, wetting, and softening activities. These biomolecules are particularly valuable in industrial applications because they are biodegradable, renewable, and often less toxic than synthetic alternatives.

Surfactants derived from plants are widely used in several types of products:

Household cleaning products and detergents:

- Examples: dishwashing liquids, laundry detergents, and surface cleaners.

Plant-based surfactants improve cleaning efficiency and foaming properties while being environmentally friendly.

Personal hygiene products:

- Examples: soaps, shampoos, body washes, and facial cleansers.

They act as emulsifiers and gentle cleansing agents suitable for skin contact.

Wetting agents for agricultural products:

Surfactants are used as adjuvants in phytosanitary formulations, improving the distribution and adherence of pesticides or herbicides on plant surfaces.

Textile industry products:

Surfactants help in scouring, dyeing, and finishing processes, improving fiber wettability, dye penetration, and fabric softness.

The production of plant-based surfactants relies on chemical or enzymatic modification of plant oils, sugars, or proteins. This allows manufacturers to tailor their properties for specific industrial applications, combining efficiency, safety, and environmental sustainability.

3.3.2. Bio-solvents

Definition

Bio-solvents are solvents whose active components are derived from plant biomass. Compared with solvents of fossil origin, they exhibit favorable ecotoxicological properties, including low toxicity, high biodegradability, and reduced environmental impact. These characteristics make them increasingly attractive as sustainable alternatives in industrial applications.

Bio-solvents are used to dissolve, degrease, dilute, or extract substances without altering the chemical formulation or functional properties of the final product see Table 3.2. Depending on their physicochemical characteristics, they are found in various industrial sectors:

Degreasing agents:

- Used for cleaning metal surfaces, mechanical parts, and textiles.
- Plant-based solvents efficiently remove oils and greases while limiting environmental contamination.

Adjuvants and diluents:

- Applied in paints, varnishes, inks, adhesives, and pesticide formulations.
- They improve fluidity, dispersion, and application performance of the products.

Reaction media:

- Used as solvents in chemical and pharmaceutical processes, including the formulation of phytosanitary products.
- Bio-solvents can replace conventional organic solvents while maintaining reaction efficiency and safety.

Carriers and supports:

- Employed in perfumes, cosmetics, and medicinal formulations to dissolve and stabilize active compounds

Overall, the use of bio-solvents illustrates the growing industrial valorization of plant-derived biomolecules, contributing to greener chemistry, improved worker safety, and environmental sustainability.

Table 3.2 : Examples of Plant-Derived Bio-solvents and Their Industrial Uses

Bio-solvent	Plant origin	Main industrial applications
Ethanol	Sugarcane, corn, wheat (<i>Saccharum officinarum</i> , <i>Zea mays</i> , <i>Triticum</i> spp.) (Fermentation)	Pharmaceuticals, perfumes, cosmetics, disinfectants, food industry
Ethyl lactate	Fermented plant sugars (corn, sugar beet)	Paints, inks, coatings, cleaning products, pharmaceutical formulations
D-Limonene	Citrus peels (<i>Citrus</i> spp.)	Metal degreasing, surface cleaners, pesticides, fragrance carrier
Glycerol (glycerin)	Vegetable oils (soybean, rapeseed)	Cosmetics, pharmaceuticals, food products, humectant and solvent
Methyl soyate	Soybean oil (<i>Glycine max</i>)	Industrial degreasers, inks, coatings, agricultural formulations
Terpenes (α-pinene, cineole, etc.)	Essential oils (pine, eucalyptus, citrus)	Green solvents, reaction media, perfumes, cleaning products

3.4. Cosmetics

The cosmetics industry makes extensive use of plant-derived biomolecules, particularly those obtained from cereals, which provide a wide range of functional and active ingredients. One of the most widely used self-tanning agents in the world, **dihydroxyacetone (DHA)**, is produced from plant sugars, commonly derived from cereals. DHA reacts with amino acids in the outer layers of the skin, producing a temporary tanning effect without exposure to ultraviolet radiation.

Cereal-derived biomolecules contribute to cosmetics beyond self-tanning applications. Wheat gluten-derived ingredients are used for their repairing, protective, and nourishing properties, helping to improve skin elasticity and hydration. These compounds are also valued in hair care formulations for their film-forming and strengthening effects.

Starch, another important plant biomolecule, is widely appreciated for its emulsifying, foaming, and absorbent properties. It is commonly used in cosmetic and oral-care products, where it helps stabilize formulations. For example, in toothpaste, starch plays a key role in maintaining texture and preventing hardening inside the tube.

Overall, the application of plant-derived biomolecules in the bio-industries is rapidly expanding. This growing interest opens new opportunities for the exploitation of these natural compounds in innovative cosmetic formulations, beyond the traditional uses previously mentioned, while responding to increasing consumer demand for natural and sustainable products.

* *

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End chapter questions

- Name three oilseed crops and their scientific names ?
- Explain the main uses of sugar crops in both food and industrial applications ?
- Give two examples of starch (amylaceous) crops and describe one industrial use for each ?
- Identify two textile crops and explain why their fibers are valuable for industry ?
- List three stimulant crops and their main active compounds ?
- Name three industrial vegetables and describe how they are processed for industrial use ?
- Give three examples of condiment crops and explain their main applications ?
- Name two perfume/aromatic plants and describe their main industrial uses ?
- List three crops used for alcohol production and explain the difference between food alcohol and bioethanol applications ?
- Explain the difference between rapeseed and canola in terms of oil composition and industrial use ?
- Give three examples of medicinal plants and describe one bioactive compound and its application for each ?
- Define industrial crops and explain the key characteristics that differentiate them from other types of crops ?
- Explain how plant-derived biomolecules are transformed and valorized in the agro-food industry, distinguishing between primary and advanced transformations ?
- Discuss the importance of secondary metabolites in the pharmaceutical industry and explain why plants remain a major source of therapeutic compounds ?
- Describe the role of plant-based surfactants and explain why they are increasingly preferred over petroleum-derived surfactants ?
- Explain what bio-solvents are and discuss their advantages in terms of environmental and toxicological properties ?
- Illustrate the industrial applications of bio-solvents using concrete examples of plant-derived compounds ?
- Explain the role of cereal-derived biomolecules in cosmetic formulations, highlighting their functional and biological properties ?
- Discuss the importance of starch as a multifunctional biomolecule in industrial applications ?
- Explain how plant biomolecules contribute to sustainable development and green chemistry ?
- Compare the use of plant-derived biomolecules in the pharmaceutical and cosmetic industries ?
- Explain why plant-based bio-industries are considered a strategic sector for the future ?
- Discuss the challenges and limitations associated with the industrial exploitation of plant-derived biomolecules ?
- Using examples, explain how plant biomolecules can replace fossil-based compounds without compromising industrial performance ?

Extraction and isolation of constituents (fibers; textiles; sugar; proteins; lipids and starch)

IV

At the end of this chapter, students should be able to

- Define extraction and isolation of natural constituents.
- Explain how the nature of fibers, sugars, proteins, lipids, and starch determines the extraction method.
- Apply appropriate extraction techniques to each class of natural constituent.
- Compare extraction methods used for different constituents.
- Justify the selection of an extraction process for a given natural substance.

The extraction and isolation of natural constituents represent fundamental operations in bio-industries. These processes aim to separate valuable components from natural raw materials of plant or biological origin and convert them into usable products for food, textile, pharmaceutical, cosmetic, and biotechnological applications. The efficiency of extraction depends on the nature of the raw material, the target compound, and the applied technique.

1. Extraction and isolation of plant fibers

1.1. Plant fibers

1.1.1. Structure

In terms of utilization, there are two general classifications of plants producing natural fibers:

primary and secondary.

The primary plants are those grown for their fiber contents while secondary plants are those where the fibers come as a by-product from some other preliminary utilization. Jute, kenaf, hemp, sisal, and cotton are examples of primary plants while pineapple, cereal, stalks, agave, oil palm, and coir are examples of secondary plants.

Natural fibers derived from plants mainly consist of cellulose, hemicellulose, lignin, pectin, and other waxy substances, as shown in Figure 4.1 In various applications, natural fibers extracted from plants are used as reinforcements in both thermoplastic and thermoset composites.

Cellulose is a highly crystalline structure which contains as much as 80% of crystalline regions. Hemicellulose is made up of highly branched polysaccharides attached to the cellulose after the removal of pectin. Lignin is amorphous, stiffens the cell walls, and acts as a protective barrier for the cellulose.

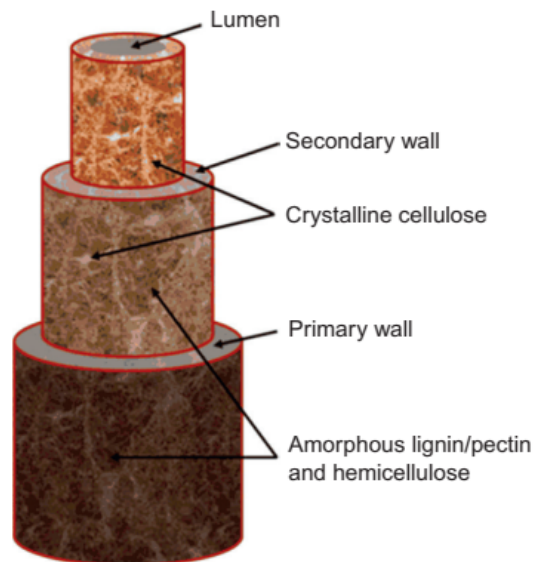


Figure 4.1 Structure of a plant fiber

1.1.2. Chemical composition

The basic chemical structures of cellulose in all plant-based fibers are similar, but they have different degrees of polymerization whereas the cell geometry of each type of celluloses varies with the fibers. Different fibers, differing growth conditions, and different testing methods used by different studies mean that it is difficult to present one table that lists all the fiber properties. However, common chemical compositions of some lignocellulose fibers are listed in Table 4.1.

Cellulose is the most important structural component in plant natural fibers; however, thermal resistance of cellulose is poor. The other important factors determining the overall properties of plant fibers are their structure, chemical composition, microfibrillar angle, cell dimensions, and fiber defects .

Table 4.1 Chemical Composition of Some Common Natural Plant Fibers

Fiber	Cellulose (wt%)	Hemicellulose (wt%)	Lignin (wt%)	Waxes (wt%)
Bagasse	55.2	16.8	25.3	–
Bamboo	26–43	30	21–31	–
Flax	71	18.6–20.6	2.2	1.5
Kenaf	72	20.3	9	–
Jute	61–71	14–20	12–13	0.5
Hemp	68	15	10	0.8
Ramie	68.6–76.2	13–16	0.6–0.7	0.3
Abaca	56–63	20–25	7–9	3
Sisal	65	12	9.9	2
Coir	32–43	0.15–0.25	40–45	–

1.1.3. Main sources of plant fibers

A general classification of natural lignocellulosic fibers obtained from different parts of plants is given in Table 4.2. Among these, the most widely used plant fibers include cotton, sisal, jute, bamboo and wood. A brief outline of the sources of these and other fibers is given below see Figure 4.2. Subsequent sections discuss the main methods of extraction for a number of plant fibers.

Table 4.2 Classification of natural fibers and their sources

<i>Bast</i>	<i>Leaf</i>	<i>Seed</i>					<i>Core</i>	<i>Grass/reeds</i>	<i>Other</i>
		<i>Fibers</i>	<i>Pod</i>	<i>Husk</i>	<i>Fruit</i>	<i>Hulls</i>			
Hemp	Pineapple	Cotton					Kenaf	Wheat	Wood
Jute	Sisal		Kapok				Ramie	Oat	Roots
Flax	Agava		Loofah				Hemp	Barley	Galmpi
Kenaf	Henequen		Milk weed				Flax	Rice	
Jute	Curaua			Coir	Oil palm			Bamboo	
Mesta	Banana					Rice		Bagasse	
Urena	Abaca					Oat		Corn	
Roselle	Palm					Wheat		Rape	
	Cabuja					Rye		Rye	
	Albardine							Esparto	
	Raphia							Sabai	
	Curauá							Canary grass	

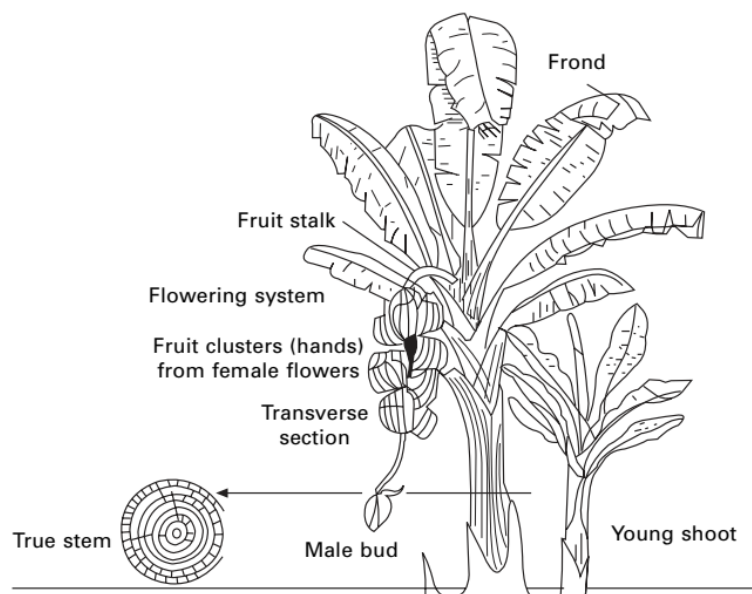
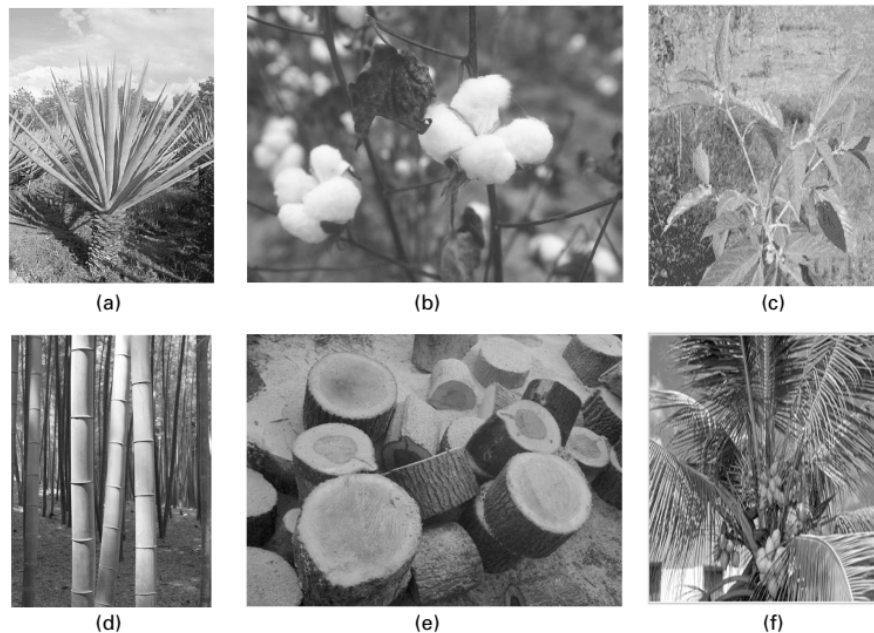


Figure 4.2 Sources of plant fibers; (a) sisal; (b) cotton; (c) jute; (d) bamboo;

a) Jute

Jute is a lignocellulosic fiber from *Corchorus* plants (Malvaceae), used both as textile and wood. Classified as a bast fiber, it mainly consists of cellulose (64 %), hemicellulose (12 %), and lignin (12 %), with minor amounts of pectin, wax, and water. The fiber is made of multilayered cells: crystalline cellulose microfibrils are bound by amorphous lignin and hemicellulose, with composition and microfibril orientation varying across cell walls.

b) Sisal

Sisal fiber is extracted from the leaves of *Agave sisalana*. In India, four varieties exist: *Sisalana*, *Vergross*, *Istle*, and *Natale*—with the first two yielding more fiber. Fiber content varies with plant age and source. Leaves contain 87 % moisture, 4 % fiber, 0.75 % cuticle, and 8 % other dry matter. Fibers are 60–120 mm long, with broad, blunt ends. Cells are angular, 500–6000 μm long and 5–40 μm wide, giving a maximum aspect ratio of 150. Calcium oxalate crystals are circular in parenchyma and often packed with tiny globules.

c) Bamboo

Bamboo belongs to the grass family Poaceae, sub-family Bambusoideae, tribe Bambuseae. It consists of cellulosic fibers embedded in a lignin matrix.

Two types of cells exist in bamboo – matrix tissue cells (leptodermous) and sclerenchyma cells which are enveloped in the matrix tissue. Vascular bundles made up of sclerenchyma cells act as reinforcement in bamboo. A vascular bundle is made up of several phloem fibers, and a phloem fiber consists of several layers of pillar fibers. Microfibers in each layer of the pillar fibers are spirally arranged at a fixed spiral angle, which varies for different layers of pillar fibers. The main chemical constituents of bamboo are cellulose, hemicellulose and lignin. Hemicellulose and cellulose, present in the form of holocellulose in bamboo, contribute more than 50 % of the total chemical constituents present in bamboo.

d) Wood

Wood is derived from shrubs and trees. It is a heterogeneous, hygroscopic, cellular and anisotropic solid material composed of cellulose (40–50 %) and hemicellulose (15–25 %) held together by lignin (15–30 %). It is commonly classified as either softwood (e.g. pine) or hardwood (e.g. oak). Softwood species comprise wood cells, mostly of one kind, tracheid, that make the material more uniform in structure than hardwoods. There are no vessels (pores) in softwood. Hardwoods are more or less filled with vessels.

e) Cotton

Cotton belongs to the botanical genus *Gossypium* and is a member of the sub-tribe Hibisceae, family Malvaceae. Cotton fiber grows around the seeds of the plant and consists of pure cellulose. The typical arrangement of cellulose gives cotton fibers strength and absorbent characteristics. The fibers are made up of a number of layers whose structure resembles the coils in a spring.

f) Banana

Banana (*Musa*, Musaceae) is a giant herb, often mistaken for a tree, with a stem formed from overlapping leaf bases. Each stem fruits once, then is replaced by suckers. It grows in tropical regions (30° N–30° S) and is cultivated both in fields and backyards. Fibers, extracted from the stem, are obtained from four varieties—Sentuluvan (red fiber), Aethalpalal, Rasagatali, and Palayankottai (white fiber)—mainly in Southern India. Soft fibers are blended with cotton, silk, wool, or synthetics for decorative items, while moderately soft fibers are used for twines, hessian, linoleum backings, and utility items. Coarse fibers serve for carpets, doormats, brushes, and cushions.

1.2. Extraction process for natural fibers

Retting is separation and extraction of fibers from nonfibrous tissues and a woody piece of stem through detachment, disintegration, and deterioration of pectins, gums, and different adhesive substances. Retting can be divided into organic, mechanical, substance, and physical fiber separation processes. Property of fiber is mostly controlled by productivity of retting procedure. In retting, the most essential factor is that pectin materials are separated and fibers are liberated. Fiber quality is reliant on an appropriate extraction process conducted in various regular conditions and durations of retting. In general Fiber separation and extraction process majorly affect the fiber yield and quality. It impacts the structure, chemical composition, and properties of fibers.

1.2.1. Biological retting

Biological retting consists of natural and artificial retting. Natural retting includes dew or field retting and cool water retting. Dew or field retting involves retting in areas that have suitable humidity and temperature ranges. After being mown, harvest must remain on the fields until microorganisms have isolated fibers from cortex and xylem. After retting, the stalk is dried and baled.

Retting process must be ceased at the correct time to avert over-retting. Meanwhile, under-retting causes difficulty in further isolation of fibers. Hence, it is important to screen the retting procedure to guarantee quality of fibers. Additionally, an adjusted field-retting process is a thermally incited stand-retting process.

a) Key microorganisms include in biological retting

Key microorganisms include *Clostridium* species, *Pseudomonas*, *Pantoea*, *Sphingomonas*, *Achromobacter*, and fungi like *Aspergillus*, *Penicillium*, and *Cladosporium*, with different microbes dominating at different stages of the process.

1.2.2. Mechanical or green retting

Isolating bast fiber from plant straw is a significantly less complicated and more practical option. Crude material for this method is either field dried or marginally retted plant straw. Bast fibers are isolated from the woody part of plants via mechanical means. Weather dependent varieties of fiber quality are ignored in this technique. The machine collects green plants, expels leafy, low fiber top part of the

plant, ribbons the bark, packages the strips, and ties the ribbon groups. Ribboning

expels bark from core material and a portion of bark called ribbons. A similar procedure is decortication, which is the expulsion of core from bark. The first goal of ribboners/decorticators was to reap the bark for its significant bast fiber and dispose of undesirable core material.

1.2.3. Physical retting

Physical retting incorporates ultrasound and steam blast strategy. In ultrasound retting, stems acquired after reaping are broken and washed. Somewhat squashed stems are then submerged in heated water that contains some alkali and surfactants before being presented to extreme ultrasound. This continuous procedure isolates hurds from fiber. Steam blast strategy on the other hand is another reasonable option to the conventional field-retting methodology. Under pressure and expanded temperature, steam and added substances enters fiber interspaces of bast fiber packs. Subsequent abrupt relaxation of steam causes a powerful separation of bast fiber composite, which deteriorates it into fine fibers.

1.2.4. Chemical and surfactant retting

Chemical and surfactant retting alludes all retting procedures in which straw is submerged in warmed tanks containing water mixed with corrosive sulfuric acid, chlorinated lime, sodium or potassium hydroxide, and soda ash remains to break up pectin at a high temperature and weight. Utilization of surface dynamic operators in retting permits basic expulsion of undesirable noncellulosic parts sticking to fibers via scattering and emulsion-shaping procedures. Moreover, oxygen introduced in a controlled condition aids in dying and shining of fibers.

1.2.5. Summary and comparison of retting techniques

Fiber collected via physical-chemical technique of retting seems to be insignificantly coarser, uneven in the vibe, and is solid. Nevertheless, gravimetric purity values do not vary from that of fiber retted by bacteria. After drying, it is necessary to mollify fiber strands by rubbing it with hands to uncover and remove its stiffness. A cationic softener may be used at a 0.2% proportion to the weight of the fiber. In addition, ammonium oxalate and sodium sulfate were found to be compatible, as in chemical retting in which fibers are extracted under controlled circumstances. If fiber properties are not affected by the treatment, it may be adopted as a standard fiber extraction process. Nonetheless, chemical retting produces high quality fibers but increases cost of the final product due to high consumption of chemicals and energy.

1.2.6. Applications

Lignocellulosic fibers are one of the natural or plant based fibers commonly chosen as the reinforcement part in polymer composites. Other examples of plant based fibers are abaca, kenaf, jute, and many more. Plant based fibers are highly beneficial due to many factors such as cost effectiveness, highly availability, non-abrasive, low density, good mechanical properties, and decomposability.

a) Automotive applications

Besides biodegradability, plant based fibers can act as a good insulator in thermal or acoustic applications . Due to the insulation behavior, plant based fibers reinforced composite are applied in many interior parts of automotive like cushioned seats, door panels and cabin lining.

b) Construction industry

The advantageous properties of plant based fibers such as lightweight, good thermal and acoustic insulation as well as stiffness are proven likewise useful in the construction industry. Therefore, the plant based fibers are commonly used in the making of construction materials like doorframes, partitioning, false ceilings, and surface paneling besides the useful molding compound in the sector of housing.

c) Other applications

The existence of plant based fibers provides opportunities not only in big industries like automotive and construction but also **tourism, fashion, agriculture** as well as small businesses developed in rural area. Products like packaging, cradles and fishing baskets are normally manufactured in a rural area. As for the tourism industry, this kind of fiber is normally applied in spa products handicrafts. In fashion, plant based fibers are also used to make belts and slippers. Additionally, bamboo fibers are normally made into clothing for multiple activities. Bamboo fibers are also used to make luxurious sheets, towels, and quality hand-made papers. In the agriculture industry, plant based fibers are normally utilized for geotextiles application. Geotextiles are fabrics woven that function as a soil protector from erosions and weeds.

2. Extraction of sugars

The goal of sugar extraction is to liberate soluble carbohydrates from the plant matrix into a liquid phase. This typically involves:

2.1. Principles of Sugar Extraction

2.1.1. Physical Preparation

Drying and grinding: Reduces particle size, increases surface area for solvent penetration.

Crushing/maceration: Breaks cell walls to assist the solvent in accessing intracellular sugars.

Physical pretreatment improves extraction yield and kinetics.

2.1.2. Solvent Selection

Aqueous solvents (water or water–alcohol mixtures) are most common for carbohydrates due to their high polarity.

Alcoholic solvents (e.g., 80 % ethanol) reduce co-extraction of proteins and lipids and stabilize extracted sugars.

Solvent choice can influence extraction efficiency and selectivity for different sugars or impurities.

2.1.3. Temperature and Time

Elevated temperatures increase solubility and diffusion rates.

Longer extraction durations often increase yield but risk degradation or microbial growth if uncontrolled.

Optimization depends on matrix and sugar stability.

2.2. Classical Extraction Techniques

Several standardized approaches are used to extract sugars:

2.2.1. Hot Water Extraction

Hot water solubilizes free sugars effectively from soft plant tissues. Water extraction can be enhanced by agitation and repeated extractions. Water often provides the highest free sugar content in many plant matrices

2.2.2. Hydrolysis Techniques

Many plant carbohydrates (e.g., cellulose, hemicellulose) are bound in complex structures. Hydrolysis, especially acid hydrolysis, breaks glycosidic linkages:

Concentrated acid hydrolysis (e.g., sulfuric acid) decrystallizes cellulose and releases sugars such as glucose and xylose from lignocellulosic biomass. This method can recover a high fraction (78-96 %) of total extractable sugars when conditions (acid concentration, temperature, time) are optimized.

Two-step methods improve yield by first swelling the matrix and then cleaving bonds progressively.

2.2.3. Alternative Pretreatments

Modern pretreatments (alkaline, enzymatic, hydrothermal) are designed to improve accessibility of polysaccharides before extraction:

Alkali pretreatment degrades ester and glycosidic bonds, enhancing sugar release in subsequent steps.

Enzymatic hydrolysis employs enzymes (e.g., cellulases, hemicellulases) under mild conditions to specifically release fermentable sugars with less degradation.

2.3. Clarification and Isolation

After extraction, the liquid contains sugars along with pigments, proteins, and other soluble compounds. Clarification and isolation often involve:

2.3.1. Filtration and Centrifugation

Removes insoluble debris and suspended solids.

Prepares extract for further purification or analysis.

2.3.2. Evaporation/Concentration

Reduces volume, increases sugar concentration.

Must be controlled to avoid thermal degradation.

2.3.3. Precipitation or Solvent Partitioning

Adding non-solvent (e.g., ethanol) can precipitate polysaccharides or remove undesired components.

Phase separation techniques help isolate sugar-rich fractions.

2.3.4. Chromatographic Separation

For analytical isolation, high-resolution methods are employed:

High-Performance Liquid Chromatography (HPLC) is widely used to separate and quantify individual sugars from mixtures. It relies on differences in interactions between sample components and the stationary phase in the column.

Coupled with detectors such as refractive index (RI) or evaporative light scattering detector (ELSD), HPLC can quantify glucose, fructose and sucrose with high precision

2.3.5. Analytical Quantification

Quantification of extracted sugars is critical in research and industrial contexts:

Refractive Index Detection (RID): Common for carbohydrates due to sensitivity to changes in refractive index of eluents.

UV/Vis Detection: Less effective for non-chromophoric sugars unless derivatized.

Mass Spectrometry (MS): Offers high specificity when coupled with liquid chromatography for complex mixtures.

Proper calibration with standards ensures accurate concentration determination.

2.4. Applications and Examples

2.4.1. Laboratory Research

Plant physiology studies often require precise sugar profiling (e.g., free vs bound sugars).

Extraction protocols are tailored to target analytes and minimize degradation.

2.4.2. Food and Bioproduct Industries

Cane and beet sugar production involve hot water extraction and clarification steps on an industrial scale.

Extracted sugar solutions are concentrated and crystallized for commercial sugar production.

2.4.3. Biomass and Biofuels

Lignocellulosic biomass pretreatment and hydrolysis are essential for converting polysaccharides into fermentable sugars for bioethanol production.

* *

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Extraction and Isolation of Sugars

1. Introduction

- Sugars are major primary metabolites in plants:
 - Monosaccharides (*glucose, fructose*)
 - Disaccharides (*sucrose*)
 - Polysaccharides
- Extraction requires consideration of matrix and sugar types.

2. Principles of Sugar Extraction

2.1 Physical Preparation

- Drying & Grinding
- Cell Wall Breakdown

2.2 Solvent Selection:

- Water, Ethanol

3. Classical Extraction Techniques

3.1 Hot Water & Acid Hydrolysis Extraction

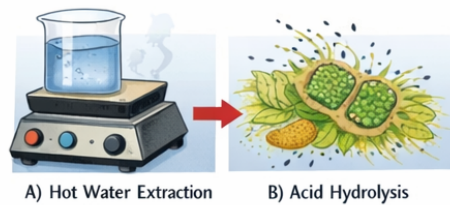
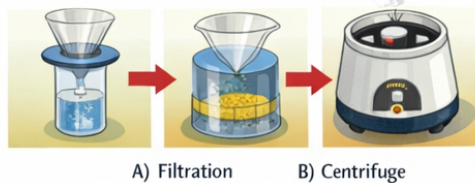


Fig. 2. Extraction methods.

4. Clarification and Isolation

4.1 Filtration & Centrifugation

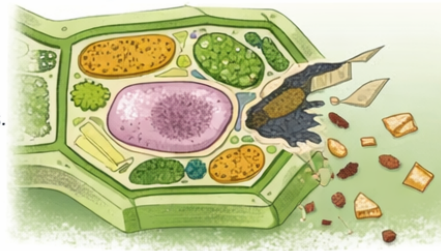


A) Filtration B) Centrifuge

6. Applications & Examples



Fig. 1. Plant cell breakdown

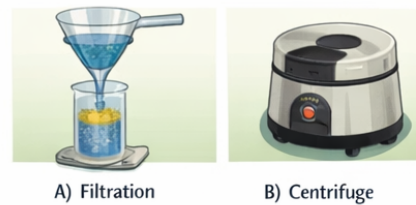


2.2 Solvent Selection: Water, Ethanol

2.3 Temperature & Time: $Y = k \cdot e^{-\frac{E_a}{RT}} t$

4. Clarification and Isolation

4.1 Filtration & Centrifugation



A) Filtration B) Centrifuge

4.2 Chromatographic Separation

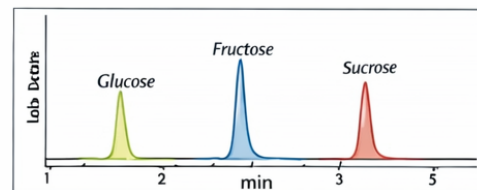
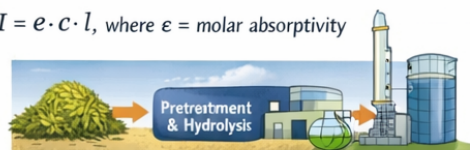


Fig. 4. HPLC chromatogram: Glucose, Fructose, Sucrose

5. Analytical Quantification

Sugars + Reagent → Colored Product

$I = e \cdot c \cdot l$, where ϵ = molar absorptivity



References for Further Reading: Casas-Godoy et al., Hong et al., HPLC Method Development

Figure 4.3 Steps of sugar processing

3. Extraction and Isolation of Plant Proteins

Plant proteins constitute a major source of nutritional, functional, and industrial biomolecules. They are found in seeds, leaves, stems, and roots, where they play roles in storage, metabolism, and structural support. Unlike animal proteins, plant proteins are often embedded in complex cell wall matrices rich in cellulose, hemicellulose, lignin, and phenolic compounds, which makes their extraction particularly challenging. Efficient extraction and isolation strategies are therefore essential to recover plant proteins with acceptable yield, purity, and functionality.

3.1. Characteristics of Plant Proteins

Plant proteins are highly diverse and can be broadly classified into storage proteins (e.g., globulins and prolamins in seeds) and metabolic or structural proteins (e.g., enzymes and membrane-associated proteins in leaves). Their solubility depends strongly on pH, ionic strength, and molecular structure. In many cases, plant proteins coexist with antinutritional factors such as polyphenols, tannins, and polysaccharides, which may interfere with extraction and purification.

3.2. Principles of Plant Protein Extraction

The extraction of plant proteins aims to disrupt the plant tissue, solubilize proteins, and minimize degradation or denaturation.

3.2.1. Sample Preparation

Plant materials are first:

Washed and cleaned to remove dust and soil,

Dried or processed fresh, depending on protein stability,

Ground into fine particles to increase surface area and facilitate solvent penetration.

For leafy materials, freezing followed by grinding may be used to preserve protein integrity.

3.2.2. Role of pH and Ionic Strength

Protein solubility is minimal at the isoelectric point (pI), where the net charge of the protein is zero. Therefore, extraction is generally carried out at alkaline or acidic pH values away from the pI, enhancing protein solubilization. Moderate salt concentrations can further improve solubility by reducing electrostatic interactions between proteins and cell wall components.

3.3. Extraction Methods for Plant Proteins

3.3.1. Aqueous Buffer Extraction

The most common approach involves the use of aqueous buffer solutions (e.g., phosphate or Tris-HCl buffers). These buffers stabilize pH and help maintain protein structure. Reducing agents and protease inhibitors are often added to prevent oxidation and enzymatic degradation during extraction.

3.3.2. Alkaline Extraction

Alkaline extraction is widely applied in plant protein recovery, particularly from seeds and agricultural residues. At alkaline pH, proteins become highly soluble due to increased electrostatic repulsion. This method is effective but must be carefully controlled to avoid excessive denaturation or modification of amino acid residues.

3.3.3. Enzyme-Assisted Extraction

Enzymatic treatments using cellulases, hemicellulases, or pectinases partially degrade the plant cell wall, improving protein release under mild conditions. This approach enhances yield while preserving protein functionality and is increasingly used in sustainable and green extraction processes.

3.4. Clarification and Isolation of Plant Proteins

3.4.1. Removal of Insoluble Material

Following extraction, the crude extract contains cell debris and insoluble polysaccharides. These are removed by filtration or centrifugation, producing a clarified protein solution.

3.4.2. Isoelectric Precipitation

Protein isolation is commonly achieved by adjusting the pH of the extract to the isoelectric point of the target proteins. At this pH, proteins aggregate and precipitate, allowing their separation by centrifugation. The precipitated proteins are then washed and redissolved in a suitable buffer.

3.4.3. Desalting and Concentration

Dialysis or ultrafiltration is used to remove salts and low-molecular-weight compounds, yielding a more purified protein fraction suitable for further processing or analysis.

3.5. Purification Techniques and Analytical Characterization

3.5.1. Purification Technique

For higher purity, plant proteins can be further purified using chromatographic methods:

- Ion-exchange chromatography, exploiting differences in protein charge.
- Size-exclusion chromatography, separating proteins based on molecular size.
- Affinity-based approaches, used selectively for specific plant enzymes or binding proteins.

These techniques are primarily applied in research and high-value bioproducts.

3.5.2. Analytical Characterization

Plant protein extracts are routinely characterized using:

- Colorimetric assays for protein quantification,
- Electrophoretic techniques (e.g., SDS-PAGE) to assess molecular weight and purity,
- Spectroscopic and mass spectrometric methods for structural and functional analysis.

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Applications of Plant Protein Extracts

Extracted plant proteins are used in:

- Food and feed formulations, as nutritional and functional ingredients,
- Biotechnology, for enzyme production and biocatalysis,
- Pharmaceutical and cosmetic industries, as bioactive compounds and stabilizers.

Extraction and Isolation of Seed Proteins

1. Introduction

- Plant seed proteins constitute a significant proportion of dietary and industrial proteins.
- Embedded in complex cellular matrices and often associated with lipids and phytic acid, efficient protocols are needed for their extraction and isolation.

2. Characteristics of Seed Proteins

- Seed proteins are predominantly storage proteins – globulins, albumins, prolamins. Their solubility depends

3. Principles of Seed Protein Extraction

3. Sample Preparation

- Seeds are dried, ground, or defatted to reduce the interference of lipids and enhance solvent penetration.
- Grinding increases surface area for efficient ex-

$$||V = fe.|| \quad ||\epsilon \tau_0 \tilde{\gamma}_{sk} \tilde{\gamma} / \omega \tilde{\gamma}_{sk} \tilde{\gamma} / u \tilde{\tau}_{ls} \tilde{\tau}_p$$

- Extraction is optimal at pH where the solubility of seed proteins is maximum, typically $\text{pH} \approx \text{pI}$.

4. Extracting Methods for Seed Proteins

4.1 Aqueous Buffer Extraction

- Use of Phosphate, Tris-HCl, acetate buffers.

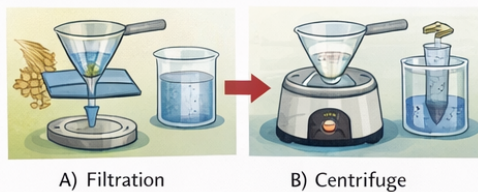
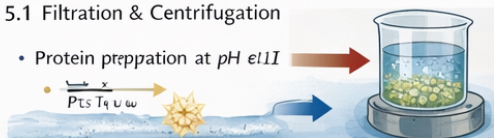


Fig. 3. Protein Separation Steps.

5. Isolation of Seed Proteins

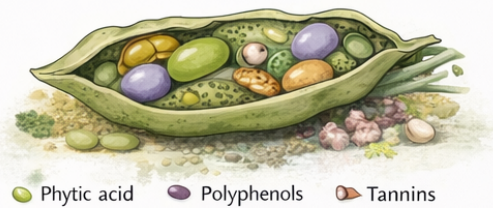
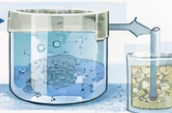
5.1 Filtration & Centrifugation

- Protein preparation at $\text{pH} \approx 11$



5.4 Enzyme-Assisted Extraction

- Enzymes (e.g. cellulase, hemicellulase, protease) degrade cell wall & matrix
- Improve protein recovery and reduce extraction harshness reduces protein polet.



Antinutritional factors: Phytic Acid, Polyphenols, Tannins

Fig. 1. Solubility $\times$ pH pI where $\frac{pI - \text{pH}}{pI - \text{pH}_{\text{max}}} = \text{maximum } pI$

4. Extracting Methods for Seed Proteins

4.1 Aqueous Buffer Extraction

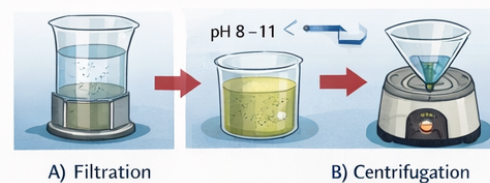


Fig. 2. Protein separation steps.

5.2 Isoelectric Precipitation

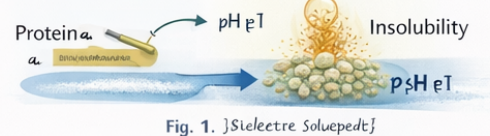
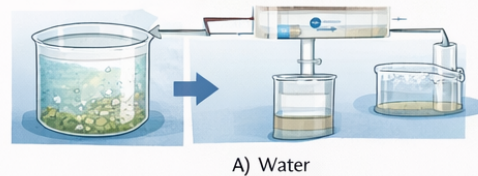


Fig. 1. Isoelectric Solubility

5.3 Dialysis & Desalting



6. Advanced Purification Techniques

- Ion-Exchange Chromatography
- Size-Exclusion chromatography
- Affinity chromatography



References for Further Reading:

- Casas-Godoy et al. (2020) Comparison of extraction technique for plant protein recovery, 1. Food Science & Technology.
- Hong et al. (2000) Optimization of seed protein extraction through pH adjustment, Biotechnology Advances.

Figure 4.4 extraction and purification of seed proteins

4. Extraction of Oils from Plant Sources

Plant-derived oils constitute one of the most important classes of natural lipids exploited by humans for nutritional, industrial, and technological purposes. They are mainly stored in seeds, fruits, and sometimes in vegetative tissues, where they serve as energy reserves for plant growth and development. Industrial extraction of vegetable oils aims to recover these lipid fractions efficiently while preserving their chemical integrity and functional properties.

Vegetable oils are primarily composed of triglycerides, accompanied by minor components such as phospholipids, free fatty acids, sterols, tocopherols, pigments, and volatile compounds. The extraction process plays a decisive role in determining oil yield, quality, stability, and suitability for downstream applications.

4.1. Involved steps in Extraction of Oils from Plant Sources

4.1.1. Plant Sources of Vegetable Oils

Vegetable oils are obtained from a wide range of oil-bearing plants, including oilseeds (soybean, sunflower, rapeseed, cottonseed), fruits (olive, palm, avocado), and nuts (peanut, coconut). The oil content varies significantly depending on plant species, cultivar, agronomic conditions, and maturity stage.

Oilseeds generally contain between 20 and 50% oil on a dry weight basis, stored within specialized cellular structures known as oil bodies or oleosomes. These lipid droplets are surrounded by a phospholipid monolayer and proteins, which protect the oil from oxidation but also influence extraction efficiency.

4.1.2. Principles of Vegetable Oil Extraction

The extraction of oils from plant materials is based on the disruption of plant tissues and the release of intracellular lipids, followed by their separation from the solid matrix. Two main principles govern industrial oil extraction:

- Mechanical separation, where pressure is applied to expel oil from crushed plant material.
- Solvent-based extraction, where lipids are dissolved in an organic solvent and subsequently recovered.

In practice, these methods are often combined to maximize oil recovery while maintaining acceptable processing costs and product quality.

a) Mechanical Extraction (Pressing)

Mechanical extraction, also known as oil pressing, is one of the oldest methods for obtaining vegetable oils. It involves cleaning, dehulling, grinding, and pressing the oil-bearing material to rupture the oil-containing cells and release the oil.

Pressing can be performed under cold or hot conditions. Cold pressing is carried out at relatively low temperatures, preserving natural antioxidants, flavors, and bioactive compounds, and is commonly used for high-value edible oils such as olive oil. However, oil yield is generally lower compared to hot pressing.

Hot pressing involves thermal pretreatment of the material prior to pressing, which reduces oil viscosity and improves yield but may cause partial degradation of heat-sensitive compounds.

Mechanical extraction is widely applied at both artisanal and industrial scales, particularly where oil quality is prioritized over maximum yield.

b) Solvent Extraction

Solvent extraction is the dominant industrial method for large-scale vegetable oil production. It is typically applied to oilseeds with moderate oil content or to press cakes remaining after mechanical extraction.

The process involves contacting finely ground plant material with a non-polar organic solvent, most commonly hexane, which selectively dissolves lipids. The resulting mixture, known as miscella, is then separated from the solid residue. Solvent recovery is achieved by evaporation and condensation, leaving behind crude oil.

Solvent extraction offers high oil recovery efficiency, often exceeding 95%, and is economically advantageous for mass production. However, it requires careful control to minimize solvent residues and environmental impact.

4.1.3. Refining of Crude Vegetable Oils

Crude oils obtained by pressing or solvent extraction contain various impurities that must be removed before consumption or industrial use. Oil refining typically includes degumming, neutralization, bleaching, and deodorization.

Degumming removes phospholipids, while neutralization eliminates free fatty acids. Bleaching reduces pigments and trace metals, and deodorization removes volatile compounds responsible for undesirable odors and flavors.

The extent of refining depends on the intended application of the oil, with edible oils requiring higher purity standards than industrial-grade oils.

4.1.4. Emerging and Green Extraction Technologies

In response to environmental and safety concerns associated with organic solvents, alternative extraction technologies are increasingly explored. **Supercritical carbon dioxide extraction** has attracted significant attention due to its non-toxicity, solvent-free nature, and ability to selectively extract lipids under mild conditions.

Other emerging approaches include **enzymatic pretreatment**, which enhances oil release by degrading cell wall components, and aqueous extraction, which reduces solvent use but poses challenges in oil separation and emulsion stability.

These technologies are particularly promising for high-value oils and functional lipid fractions.

4.1.5. Industrial Applications of Plant Oils

Extracted vegetable oils are extensively used in the food industry as cooking oils, frying media, and ingredients in processed foods. They also serve as essential raw materials in the production of margarine, shortenings, and salad dressings.

Beyond food applications, plant oils play a crucial role in the biofuel industry, where they are converted into biodiesel. They are also widely used in cosmetics, pharmaceuticals, oleochemicals, lubricants, soaps, and biodegradable materials.

The versatility of vegetable oils underscores their importance as renewable resources in a bio-based economy.

4.2. Exemple of vegetable oil production

4.2.1. Olive Oil

Olive oil is an important oil in the world edible oil basket and is ranked tenth in terms of production tonnage. It is known for its distinctive aroma and is the most pricy edible oil today. The olive trees grow mainly in the Mediterranean basin, and olive oil is the traditional oil of the region.

The oil is obtained from the fruit of olive. The fruit must be processed within 24 hours of harvesting, to prevent the excessive rise in free fatty acids. Fruit contains around 20–25% oil, and has moisture content of 45–50%.

4.2.2. Olive Oil processing

As the oil is known for its aroma, it cannot be subjected to heat processing. In fact, 'cold-pressed' olive oils are mandated to be extracted at temperatures below 27°C. Grades of cold-pressed oil depend on the FFA content, 'extra virgin oil' having less than 0.8% (or 0.5% in USA) FFA, and 'virgin oil' with up to 1.5% FFA. Oil produced with some amount of heating may be refined, to produce 'refined olive oil'. Traditionally, olive oil used to be extracted in vertical batch presses. Modern mills use high-speed decanters for oil extraction, and operate on a continuous mode (Figure 4.5).

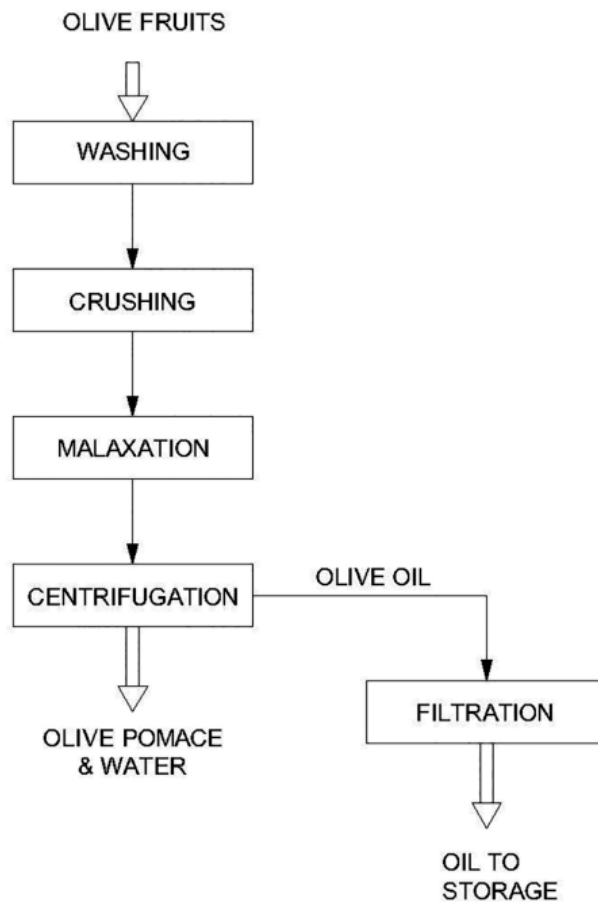


Figure 4.5 Flow Sheet for Olive Oil Production.

Pretreatment

As the olive fruits are received at the factory, they are first washed with water to remove any soil impurities. Water is sprayed onto a slow-moving belt conveyor carrying the fruit. Water is drained as the fruit is passed over a screen. The washed fruit is conveyed to a grinder to make pulp. The grinder may be a slow-rotation disk mixer, or a metal-tooth mixer, or a simple hammer mill.

The rotation speed of the grinding element is low, and so is the energy requirement, thanks to the 'soft' texture of the fruit.

Malaxation

The pulp is gently mixed ('malaxed') for 30–60min, to allow oil globules to aggregate, as also to help in aroma generation. Longer malaxing time improves oil extraction, but may result in some oxidation, and can lower the shelf life. Typical malaxing equipment is a slow moving disk or ribbon mixer. No heating is allowed during the process. Modern malaxers are nitrogen blanketed, to produce better quality oil with improved shelf life. For the production of 'refined' grade, malaxers may come with steam jackets. The malaxed pulp is then sent to the oil extraction operation.

Decantation

The extraction is accomplished by means of high-speed centrifugation, in a horizontal Decanter. These are either two-phase or three-phase decanters. For a three-phase decantation, water is added to the pulp, and then oil, water, and dry 'pomace' phases are separated. The advantage of a three-phase decanter is a single-step operation; however, a major disadvantage is the production of a voluminous water phase which must be treated to prevent pollution. Alternatively, a two-phase decanter separates the oil from a wet pomace phase.

Second extraction

This may be followed by second extraction, after addition of water to the wet pomace, in another two-phase decanter. The second extraction can add as much as 6% of the fruit oil to the 90% extracted in the first extraction. Water addition requirement is much lower due to the smaller quantity of 'pomace' in relation to the malaxed fruit.

The oil produced with two-phase decanters is of better quality due to less water addition, which allows better aroma retention, as also retention of anti-oxidant compounds.

The extracted oil phase still has to go through another centrifugation step, with bowl or disk centrifuges running at higher speeds than decanters, to remove water entrained with oil. The dry oil may be passed through a polishing filter before bottling.

The pomace contains 7–8% oil, which may be extracted, after drying, with the solvent extraction process. The oil is called '**pomace oil**'.

5. Starch extraction

Starch is an abundant polysaccharide that provides energy storage in green plants; it has become the cheapest energy source for humans. Starchy foods have been consumed by humans and their ancestors for thousands of years. Food, pharmaceutical, textile, and paper sectors all use starch. It is also used as feedstock for bioethanol and biodegradable plastics to substitute for gasoline and plastics derived from fossil fuels. Nonfood businesses are expected to have a greater demand for starch in the future than food industries

5.1. Sources of starch

Sources of starch and its content Various plants contain starch, either in their fruits, seeds, roots, leaves, or stems, with different amounts and characteristics. Cereal grains such as wheat, rice, and corn are major starch sources. Potato, cassava, and yams are potential sources of root and tuber starches, while sago provides starch in its stem. Those plants are conventional sources of starch, whereas some parts of plants, such as fruit seeds, pulses, and pseudocereals, are unconventional sources of starch. Table 4./// shows the starch content of some botanical sources and the amylose content of starches

Table 4.3 Sources of starch with their starch content

Botanical sources of starch	Starch content (%)	Amylose and amylopectin content (%)
Avocado (<i>Persea americana</i>) seed	7.8–29.3	30.41 and 69.59
Banana (<i>Musa</i> sp.)	80.35–86.76	24.41–29.08 and 70.92–75.59
Barley (<i>Hordeum vulgare</i>)	45.7–66.4	21–28.1 and 71.9–79
Breadfruit (<i>Artocarpus altilis</i>)	71.38	22.52–25.20 and 74.80–77.48
<i>Canna edulis</i>	12.74–13.63 (wb) ~63.7–68.2 (db)	19–25 and 75–81
Cassava (<i>Manihot esculenta</i>)	20–32 (wb)	16.04–26.95 and 73.05–83.96
Cassava (<i>Manihot esculenta</i>) stem	66.7	20.8 and 79.20
Corn (<i>Zea mays</i>)	86	25.25 and 74.75
Durian (<i>Durio zibethinus</i>) seed	46.2	22.76 and 77.24
Jackfruit (<i>Artocarpus heterophyllus</i>) seed	81–82.5	25.4 and 74.6
Litchi (<i>Litchi chinensis</i>) seed	40	7.70–9.60 and 90.4–92.3
Lotus (<i>Nelumbo nucifera</i>) seed	60	35–45 and 55–65
Mango (<i>Mangifera indica</i>) seed	65	16.3 and 83.7
Oat (<i>Avena sativa</i>)	60	20.5–22.7 and 77.3–79.5
Oil palm (<i>Elaeis guineensis</i>) trunk	10.37–10.86 (wb)	37.3 and 62.70
Pineapple (<i>Ananas comosus</i>) stem	77.78	35.15 and 64.85
Potato (<i>Solanum tuberosum</i>)	18.07–22.21 (wb)	18.79–22.95 and 77.05–81.21
Rice (<i>Oryza sativa</i>)	66.3–69.2	16.9–29.9 and 70.1–73.1 22.6–27.6 and 72.4–77.4
Sago (<i>Metroxylon</i> sp.)	38.97–45.4	23–31 and 69–77
Sorghum (<i>Sorghum bicolor</i>)	70–72	10.8–18.72 and 81.28–89.2
Sugar palm (<i>Arenga pinnata</i>) trunk	11.8–20.5	37.60 and 62.40
Sweet potato (<i>Ipomoea batatas</i>)	33.7–64.1 44.4–74.5	15.4–19.6 and 80.4–84.6 14.9–25.1
Taro (<i>Colocasia esculenta</i>)	73.0–76.1	17.83 and 82.17
Wheat (<i>Triticum aestivum</i>)	63	21.3 and 78.7
Yam (<i>Dioscorea</i> sp.)	40.7–63.3	15.1–27.1 and 72.9–84.1

5.1.1. Seeds and fruits (Cereal grains)

Corn (*Zea mays*), also known as maize, is the most common starch source. Corn grain contains 72% starch. Based on the ratio of amylose and amylopectin, there are three types of corns: normal, waxy, and high amylose.

Wheat (*Triticum aestivum*) is a major food staple worldwide. The wheat grain consists of four major parts: seed coat (10%), aleurone layer (2%), endosperm (83%), and germ (5%). Wheat starch is found in the endosperm and is a pure carbohydrate

Rice (*Oryza sativa*) is the staple food for over half of the world's population, especially in Asia. Starch content in rice ranges from 69% to 75%.

Sorghum (*Sorghum bicolor* L. Moench) is a cereal that can grow on dry land. Sorghum is typically classified as grain or sweet based on its final use: grain sorghum is used to make staple foods in tropical areas or alcoholic beverages, while sweet sorghum is used to make sweetener syrup.

Barley (*Hordeum vulgare* L.) is the fourth most important cereal. Barley grains contain 57.86% - 65.64% starch.

Oat (*Avena sativa*) is a cereal commonly used as livestock food. The total amylose content in oat starch has been reported at an average of 37%.

5.1.2. Seeds and fruits (Fruits)

Bananas (*Musa* spp.) are a fruit that can be used as a carbohydrate source, especially in tropical countries. Some green bananas grown in Thailand have a starch content of 62.77% - 66.90%.

Breadfruit (*Artocarpus altilis*) is a seedless tropical fruit that is green with a round shape. Breadfruit contains significant amounts of carbohydrates (84%) and starch (60% of total carbohydrates).

5.1.3. Seeds and fruits (Fruit seeds)

Some fruit seeds have been reported to contain starch. These seeds could become potential sources of starch as by-products in the food processing industry. These starches have not been widely studied and explored and are needed further elucidation because they probably have certain or special characteristics needed for some applications exp: (Lotus seed (*Nelumbo nucifera* Gaertn) 60%; Jackfruit (*Artocarpus heterophyllus*) 24.5% - 26.67%; Durian (*Durio zibethinus*) seeds 22.76%.

5.1.4. Roots, tubers, and rhizomes

Cassava (*Manihot esculenta*) is one of the world's most important crops, with Nigeria and Brazil producing most of it. The starch content of cassava is 65.71%.

Potato (*Solanum tuberosum*) tubers are an important staple food source. Potato contains 18.07% - 22.1% (wet basis) starch.

Taro (*Colocasia esculenta*) is a tropical perennial plant grown for its roots and leaves. The starch content of taro varies from 12% to 25%, depending on the variety.

Sweet potato (*Ipomoea batatas*) roots are widely recognized as nutritious food and starch sources but are still underutilized. The starch content in sweet potatoes is 52.54%

5.1.5. Stems and trunks

Sago palm (*Metroxylon* spp.) grows well in humid tropical lowlands up to 700 m in elevation. The starch yield obtained from 10- to 12-year-old sago palm trunk ranges from 18% to 23%.

Sugar palm (*Arenga pinnata*) is a multipurpose tree that grows in tropical areas of Southeast Asia. As much as 11.8% - 20.5% starch yield can be extracted from the sugar palm trunk.

Oil palm (*Elaeis guineensis*) is an important plant for producing cooking oil. The highest starch content is in the core at 3 - 4 m in height, reaching 10.37% - 10.86%.

5.2. Extraction and isolation of starch

The process for extraction and isolation of the starch essentially consists of two parts, that are disintegration and separation. For example, cereal grains such as wheat, rice, corn, and sorghum should be ground, while roots and tubers such as potato and cassava should be shredded and grated or rasped. The process is followed by the separation and purification of the starch from other parts, which could be conducted based on different sizes or weights.

5.2.1. Disintegration

Disintegration is the first main step in the extraction of starch. The objective of this step is to break down the plant tissues and cells to more easily release the starch. The disintegration process usually involves peeling, cutting, grating, rasping, grinding, and/or milling.

5.2.2. Separation and purification

The common methods of separation and purification of starch from other components are filtration, sedimentation, decantation, and centrifugation. Filtration is a separation process based on different sizes of the components to be separated. The process can be used in different mesh sizes of screens or filters. Sedimentation, decantation, and centrifugation methods are based on different weights of the components to be separated.

5.2.3. General extraction and isolation methods of starch from roots, trunks, and grains

The typical starch isolation process from root and tuber crops is shown in Figure 4.6

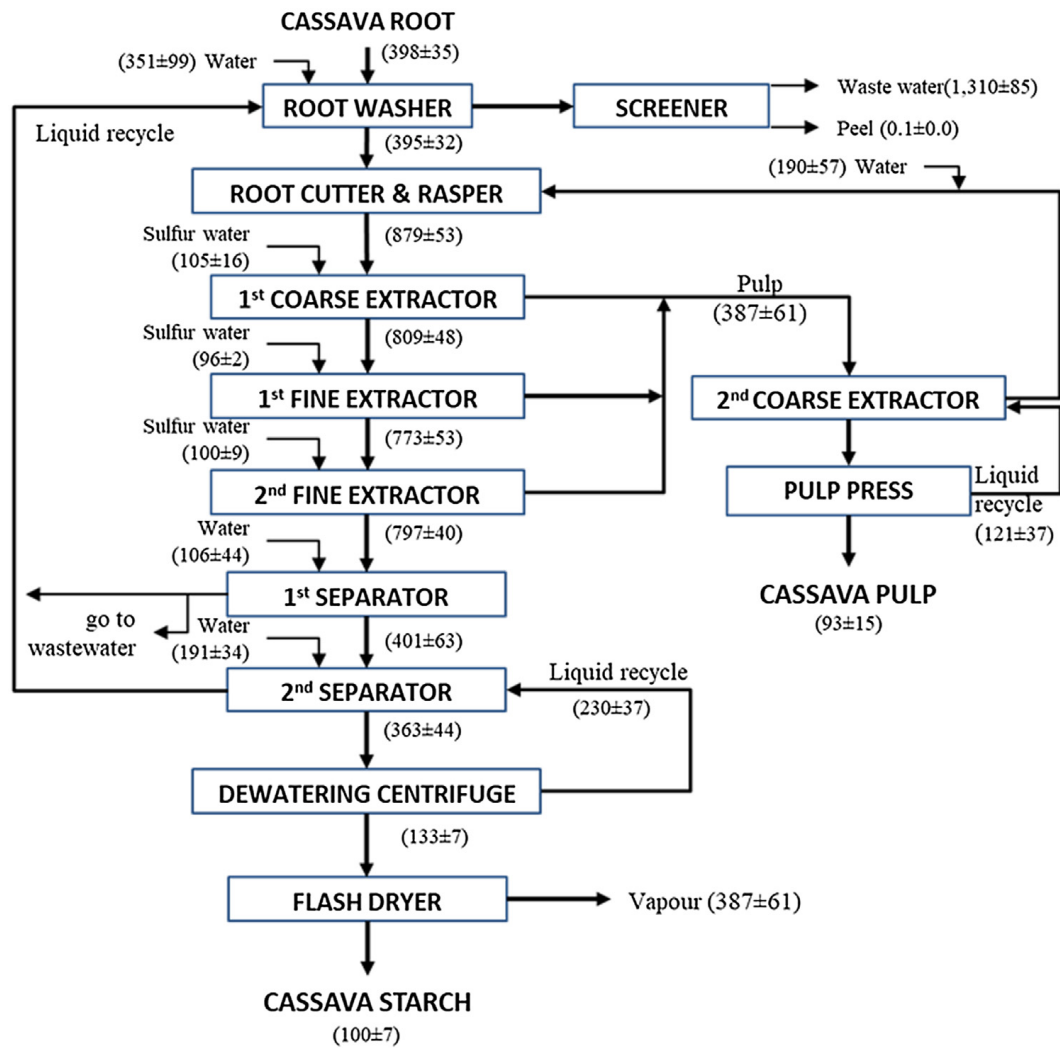


Figure 4.6 Extraction and isolation of cassava starch from cassava roots.

Figure 4.7 shows a process of starch extraction from stem sources.

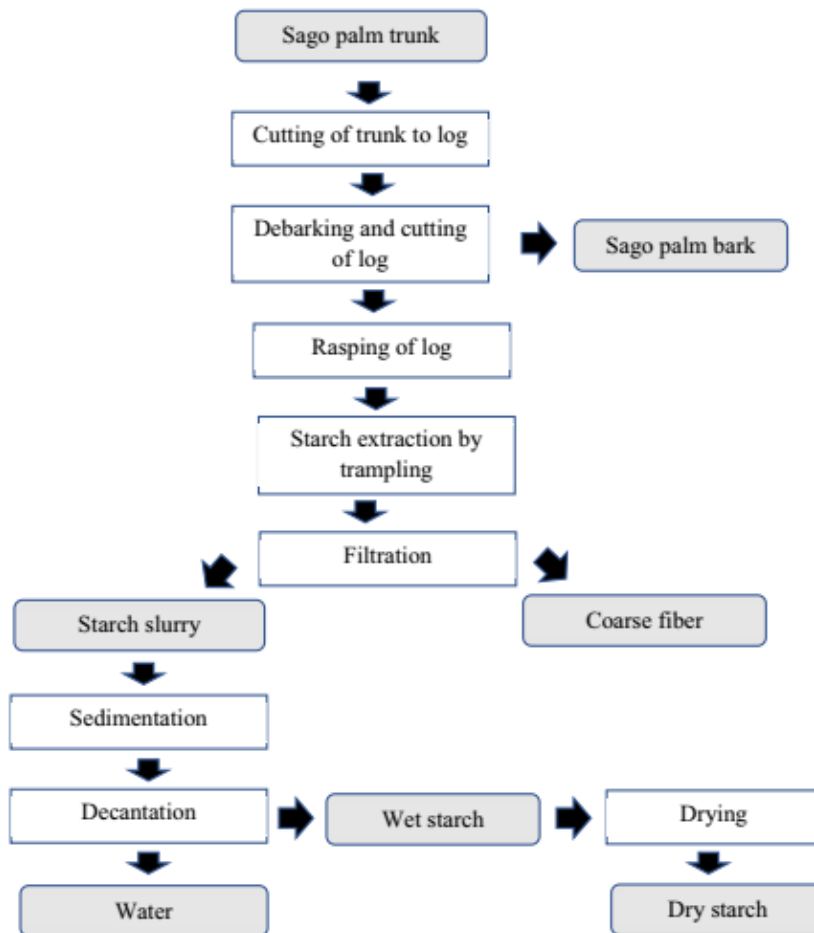
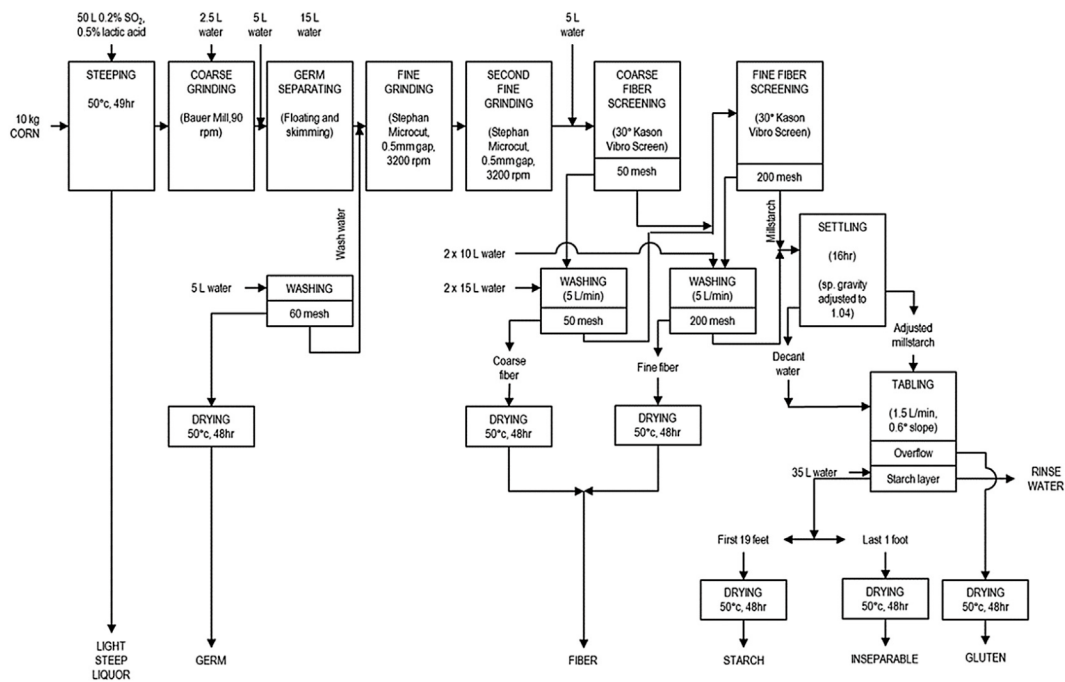


Figure 4.7 Extraction and solation of sago starch from sago palm trunks.

Figure 4.8 shows a process of starch extraction from grains.



5.2.4. Starch main applications

Common plant sources, modification technologies, and potential application of starch. Cereal-based starch, including maize starch, rice starch, wheat starch, barley starch, and sorghum starch. Tuber-based starch such as potato starch, sweet potato starch, and yam starch. The common root-based starch is cassava starch and taro starch, and green banana starch is an example of fruit-based starch. Starch modification techniques such as physical, chemical, and enzymatic modification treatments. Physical modification techniques such as high-pressure autoclave treatment, osmotic pressure treatment, and extrusion. Chemical modification approaches include oxidation, esterification, etherification, and hydroxypropylation, as well as enzymatic modifications such as dextrinization. Potential starch applications such as food stabilizers, three-dimensional food printing, prebiotic nutrients, synthesis encapsulation systems, food additives in plant-based meat, and bioplastics and edible coatings are listed in Figure 4.9



Figure 4.9 main steps of starch extraction, treatment and applications

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End chapter questions

- What are the main plant constituents commonly extracted from biomass?
- Why is pretreatment of plant material important before extraction?
- What is the role of the plant cell wall in the extraction of fibers?
- Which solvents or methods are commonly used for sugar extraction and why?
- How does protein solubility influence protein extraction?
- Why are lipids usually extracted using organic solvents?
- What are the main steps involved in starch extraction from plant sources?
- What factors affect starch purity and yield during extraction?

- How does the physical structure of plant tissues affect extraction efficiency for all constituents?
- Give one industrial application for each of the following extracts:
 - fibers, sugars, proteins, lipids, and starch.
- Why is purification an essential step after extraction?

Elaborated Products (Food, Cosmetic and Parapharmaceutical Products)



At the end of this chapter, the learner will be able to identify the main elaborated products used in the food, cosmetic, and parapharmaceutical sectors, and understand how biological components and basic industrial processes are used to produce them from raw materials.

This chapter focuses on elaborated products derived from plant resources, which represent the final stage of industrial valorization of plant-derived biomolecules. Unlike raw materials or isolated biomolecules, elaborated products result from advanced processing, formulation, stabilization, and quality control, and are intended for direct human use.

The chapter highlights how plant-based ingredients are transformed into complex food products, cosmetic formulations, and parapharmaceutical preparations, emphasizing their functional, nutritional, and biological roles. It illustrates the contribution of plant-derived biomolecules to modern bio-industries and their importance in meeting consumer demands for safe, effective, and sustainable products.

1. General Concept of Elaborated Products

1.1. Elaborated products

Definition

Elaborated products are industrial products obtained after several stages of transformation, formulation, and stabilization of raw materials of biological origin, particularly plant-derived resources. Unlike raw or minimally processed products, elaborated products are designed to meet specific functional, sensory, and safety requirements and are intended for direct use by the consumer.

Elaboration process

The elaboration process involves the combination of multiple plant-derived biomolecules, such as carbohydrates, lipids, proteins, and secondary metabolites, together with technological auxiliaries. These processes aim to enhance functionality, improve stability, ensure safety, and increase added value. As a result, elaborated products are characterized by a complex composition and a high level of industrial control.

From an industrial perspective, elaborated products represent the final stage of valorization of plant resources, where the emphasis shifts from agricultural production to processing, formulation, quality control, packaging, and regulation. Their production requires a precise understanding of the physicochemical and biological properties of plant biomolecules, as well as mastery of industrial technologies.

In addition, elaborated products are subject to strict regulatory frameworks, ensuring consumer safety, product efficacy, and quality consistency. These regulations vary depending on the sector (food, cosmetics, parapharmaceuticals) but share common principles related to traceability, labeling, and risk assessment.

Overall, elaborated products illustrate how plant-derived biomolecules are transformed into high-value goods, bridging agriculture, science, and industry, and responding to modern demands for performance, sustainability, and consumer protection.

Key idea

An elaborated product is not a raw plant or a single molecule, but a complex, formulated product obtained after several industrial steps and intended for direct consumer use.

Example : Plant-based products intended to support health:

Dietary supplements:

- Capsules containing plant extracts (polyphenols, vitamins, fibers)

Herbal syrups and tablets

- Standardized plant biomolecules with excipients

Medicinal teas and tinctures

- Controlled extraction and formulation of active compounds

They are neither raw plants nor drugs, but elaborated formulations.

1.2. Raw Materials vs Elaborated Products

1.2.1. Raw Materials

Definition

Raw materials are unprocessed or minimally processed plant resources obtained directly from agriculture or forestry. They represent the first stage of the industrial value chain.

Characteristics

- Simple composition: mostly a single type of biomolecule (starch, sugar, oil, fiber).
- Directly harvested from plants: seeds, fruits, leaves, roots, stems.
- Limited functionality in their natural form.
- Require further processing to become industrially usable.

Example

- Wheat grains (*Triticum* spp.)
- Sugarcane juice (*Saccharum officinarum*)
- Cocoa beans (*Theobroma cacao*)
- Soybeans (*Glycine max*).

Use

Serve as feedstock for the production of elaborated products, biomolecules, or industrial ingredients.

1.2.2. Elaborated Products

Definition

Elaborated products are finished or semi-finished products obtained after processing, formulation, and stabilization of raw plant materials. They are ready for consumer use or industrial application.

Characteristics

- Complex composition: combines multiple biomolecules + technological additives.
- Formulated for specific functional, sensory, or biological properties.
- Stable, safe, and regulated for industrial or consumer use.
- High added value compared to raw materials.

Example

Chocolate, biscuits, pasta

Skin creams, shampoos, toothpaste

Dietary supplements, herbal syrups, tinctures.

Use:

Serve directly the consumer market, or act as functional ingredients in other industrial products.

1.2.3. Differences summary

Table 5.1 Highlights the value addition concept: raw → processed → elaborated = higher industrial and commercial value.

Table 5.1 :Key Differences between raw material and elaborated product

Feature	Raw Materials	Elaborated Products
Definition	Natural plant-derived resources	Formulated or processed products
Composition	Single biomolecule or simple mixture	Multiple biomolecules + additives
Processing level	Minimal or none	Advanced industrial processing
Purpose	Feedstock for further processing	Ready for consumption or use
Examples	Wheat, sugarcane, cocoa beans, soybeans	Chocolate, pasta, creams, supplements

1.3. Added Value through Processing and Formulation

The concept of added value refers to the increase in functional, economic, and technological worth that occurs when raw plant materials are transformed into elaborated products. Through industrial processing and careful formulation, simple biomolecules such as sugars, starches, oils, proteins, and secondary metabolites are converted into stable, functional, and consumer-ready products.

1.3.1. Processing: Enhancing Natural Resources

Processing involves physical, chemical, or biological operations applied to raw plant materials to extract, purify, or transform biomolecules.

Examples include:

- Extraction of oils from seeds (e.g., sunflower, soybean, rapeseed)
- Refinement of sugar from sugarcane or sugar beet
- Fermentation to produce alcohol, flavors, or bioactive compounds
- Starch gelatinization for food or cosmetic applications

These processes not only increase the usability and stability of biomolecules but also allow the creation of new functionalities that are not present in the raw materials.

1.3.2. Formulation: Combining Biomolecules for Functionality

Definition

Formulation is the strategic combination of biomolecules and additives to achieve a specific purpose or performance in the final product. It ensures:

Functional properties: **emulsifying, thickening, foaming, moisturizing, protective effects**

Sensory qualities: **taste, texture, aroma, color**

Stability and shelf-life: **preventing degradation, microbial contamination, or phase separation**

Safety and compliance: **adherence to regulatory standards** for food, cosmetics, or parapharmaceuticals

Example

- Chocolate: cocoa solids + sugar + cocoa butter + emulsifiers → stable, smooth texture
- Skin cream: vegetable oils + plant extracts + emulsifiers + preservatives → moisturizing and protective
- Dietary supplement: standardized plant extract + excipients → consistent dosage and bioavailability.

Fundamental : Key Idea

Added value results from both processing and formulation: raw biomolecules are transformed into products that are functional, safe, stable, and ready for consumer use, combining scientific knowledge with industrial technology.

2. Elaborated Food Products

The food industry relies heavily on plant-derived biomolecules to create products that are safe, functional, and appealing to consumers. These products are the result of both primary and advanced transformations, where raw plant materials are converted into finished or semi-finished goods suitable for consumption.

2.1. Primary vs advanced food transformations

Food products derived from plants undergo two main types of industrial transformations: **primary transformations** and **advanced transformations**. Each stage has distinct objectives, techniques, and outcomes, contributing to the overall quality, safety, and functionality of the final product.

2.1.1. Primary Food Transformations

Definition

Primary transformations involve simple, direct processes applied to raw plant materials to make them suitable for consumption or for further industrial processing. These transformations usually do not alter the basic structure of the biomolecules but may concentrate, extract, or preserve them.

Characteristics (Table 5.2)

- Minimal or moderate technological intervention
- Preservation of natural composition as much as possible
- Focus on extracting valuable components or making raw materials usable.

Example

Table 5.2 Common Processes and Examples

Process	Purpose	Examples
Cleaning and sorting	Remove impurities, ensure quality	Wheat, soybeans, sugarcane
Milling and grinding	Reduce particle size, prepare for further processing	Wheat flour, cornmeal
Extraction	Isolate valuable components	Oil from sunflower or soybean seeds, juice from sugarcane
Fermentation	Produce alcohol or develop flavors	Beer from barley, wine from grapes, traditional soy sauces
Drying and concentration	Reduce water content for stability	Dried fruits, concentrated fruit juice

Reminder : Key idea

Primary transformations convert raw plant materials into semi-finished ingredients while preserving their natural properties for further elaboration.

2.1.2. Advanced Food Transformations

Definition

Advanced transformations involve complex industrial operations that combine multiple ingredients and technological processes to create finished, consumer-ready food products. These transformations modify, combine, or enhance the properties of plant biomolecules to achieve desired functionality, texture, taste, and shelf-life.

Characteristics:

- Multiple processing steps, often integrating heat, mechanical treatment, or chemical/enzymatic reactions
- Formulation of ingredients into stable, safe, and standardized products
- Incorporation of additives or functional biomolecules to improve sensory, nutritional, or technological properties

Example

Table 5.3 Common Processes and Examples

Process	Purpose	Examples
Blending and mixing	Combine different plant ingredients or biomolecules	Chocolate (cocoa + sugar + emulsifiers), fruit juices
Cooking and baking		Bread, biscuits, pasta

	Develop flavor, texture, and digestibility	
Emulsification	Stabilize oil-water mixtures	Mayonnaise, sauces, chocolate ganache
Extrusion and shaping	Produce uniform shapes and textures	Breakfast cereals, pasta shapes
Fortification	Improve nutritional profile	Vitamin-enriched biscuits, fiber-added drinks
Preservation technologies	Extend shelf-life and prevent spoilage	Pasteurization, canning, freeze-drying

2.2. Examples of Elaborated Food Products

Plant-derived biomolecules are transformed into a wide variety of elaborated food products through primary and advanced processing. Below, we describe key examples, highlighting industrial processes and functional roles of biomolecules.

2.2.1. Chocolate

Chocolate, is produced from cocoa beans, sugar, cocoa butter, and, optionally, milk and emulsifiers. The industrial process involves fermentation, roasting, grinding, conching, and tempering. Cocoa solids provide flavor, color, and antioxidant polyphenols, while cocoa butter contributes to texture, mouthfeel, and product stability. Sugar ensures sweetness, contributes to preservation, and acts as a fermentation substrate during initial processing. Producing chocolate requires careful control of all these factors to obtain a smooth texture, glossy appearance, and prolonged shelf-life.

2.2.2. Bakery products and pasta

Bakery products and pasta are other examples of elaborated foods. Wheat flour, water, yeast, and sometimes eggs and oils are combined, kneaded, and baked or dried to create bread, biscuits, pastries, or pasta. Starch from wheat serves as a primary energy source and gelatinizes during cooking, while gluten proteins provide structure and elasticity. Fibers contribute to digestibility and texture. The industrial process ensures uniform texture, volume, and stability, and advanced formulations allow fortification with vitamins, minerals, or fibers to enhance nutritional value.

2.2.3. Confectionery products

Confectionery products, such as candies and sweets, rely on plant sugars like sucrose, glucose, and fructose, often combined with starch, gums, fruit extracts, and natural colorants. Boiling, cooling, mixing, molding, and coating processes transform these ingredients into products with controlled texture, sweetness, and moisture content. Sugars not only provide sweetness but also regulate crystallization and preservation, while starches and gums control chewiness and moisture retention. Fruit extracts contribute flavor, color, and bioactive compounds, demonstrating the direct impact of plant biomolecules on the final product.

2.2.4. Beverages

beverages, including fruit juices, soft drinks, and fermented drinks, are produced by extracting and clarifying plant sugars, organic acids, pigments, and flavors. Pasteurization, carbonation (for soft drinks), and bottling ensure safety, stability, and consumer appeal. Sugars provide sweetness and may serve as substrates for fermentation, acids enhance flavor and preservation, and pigments contribute color and antioxidant properties. These processes illustrate how plant-derived molecules are transformed into safe, palatable, and functional beverages.

In all these examples, the combination of plant biomolecules and industrial processes demonstrates how elaborated food products are designed to meet sensory, functional, and nutritional objectives, while also ensuring stability and consumer satisfaction.

2.3. Functional Role of Plant Biomolecules in Elaborated Food Products

Plant-derived biomolecules such as sugars, starches, oils, fibers, and additives play a central role in food processing, quality, and functionality. Each molecule has specific chemical properties that are exploited during primary and advanced transformations to produce elaborated foods.

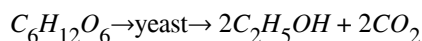
2.3.1. Sugars

Sugars (sucrose, glucose, fructose) are simple carbohydrates that serve multiple functions:

- Sweetness: direct contribution to taste.
- Preservation: sugars create osmotic pressure that limits microbial growth.
- Fermentation substrate: sugars are metabolized by yeast or bacteria to produce alcohol or acids

 *Example : Example of chemical transformation:*

- During alcoholic fermentation, glucose is converted into ethanol and carbon dioxide by yeast:



- In baking, sugars participate in Maillard reactions with amino acids, producing browning and flavor compounds:

Reducing sugar + Amino acid $\xrightarrow{\text{heat}}$ Melanoidins + flavor compounds

2.3.2. Starches

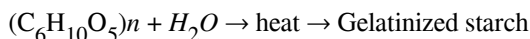
Starch is a polysaccharide composed of amylose and amylopectin. Its properties include:

- Thickening and gelling: upon heating in water, starch granules gelatinize, forming a viscous paste.
- Energy source: provides carbohydrates for human nutrition.
- Texture and stability: modifies viscosity and mouthfeel in sauces, bakery products, and desserts.

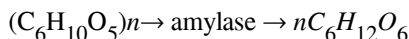
 *Complement*

Chemical transformation:

- Gelatinization involves hydration and breaking of hydrogen bonds, turning semi-crystalline granules into gel:



- Starch can also be hydrolyzed enzymatically into glucose or maltose for sweeteners:



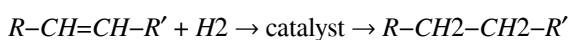
2.3.3. Oils and Fats

Oils (triglycerides) are esters of glycerol and fatty acids. Their functions include:

- Texture and mouthfeel: provide creaminess in chocolates, pastries, and spreads.
- Emulsification: when combined with lecithins or other surfactants, they stabilize oil-water mixtures.
- Flavor carrier: lipids dissolve and retain aromatic compounds.

Example of chemical transformation:

During **hydrogenation**, unsaturated fats (double bonds) can be converted to saturated fats to alter melting points:



2.3.4. Fibers

Dietary fibers (cellulose, hemicellulose, pectin) contribute to:

- Texture: improve viscosity, chewiness, and bulk in bakery products.
- Digestive health: act as prebiotics, supporting gut microbiota.
- Water retention: maintain moisture and stability in processed foods.

Pectin, for example, form gels in presence of sugar and acid, important for jams and jellies:



2.3.5. Additives and Functional Ingredients

Plant-derived additives (natural emulsifiers, stabilizers, colorants, and antioxidants) are used to:

- Stabilize emulsions: lecithin in chocolate or sauces
- Prevent oxidation: tocopherols (vitamin E) protect oils from rancidity
- Enhance color and flavor: anthocyanins, carotenoids, and plant extracts

These additives exploit chemical properties such as polarity, redox potential, or pH sensitivity to maintain product quality during processing and storage.

Attention : Key Concept

In elaborated food products, plant biomolecules are not only **nutrients** but also **functional agents**. Their chemical structure determines how they behave during processing, how they contribute to texture, flavor, stability, and nutritional quality, and how they can be transformed or combined to create high-value foods.

2.4. Preservation, Texture, Flavor, and Nutritional Enhancement in Elaborated Food Products

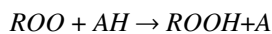
2.4.1. Preservation

Preservation ensures microbial safety, chemical stability, and shelf-life extension. Plant biomolecules and processing contribute in several ways:

- Sugars create high osmotic pressure, reducing water activity and inhibiting microbial growth.
- Acids (citric, malic) lower pH, preventing bacterial proliferation.
- Phenolic compounds and antioxidants (polyphenols, tocopherols) protect lipids and pigments from oxidation.

👉 *Example : Example of chemical protection:*

Lipid oxidation prevention by antioxidants:



where *ROO* is a lipid peroxy radical and *AH* is a plant-derived antioxidant.

Pasteurization and sterilization, while physical methods, complement these biomolecular properties to ensure long-lasting food safety.

2.4.2. Texture

Texture is determined by starch gelatinization, protein network formation, fat crystallization, and fiber content:

- **Starch gelatinization:** heated in water, starch granules swell and form a viscous gel, providing thickness and consistency.
- **Gluten network:** in bread, gluten proteins form an elastic network, trapping gas and giving volume.
- **Fat crystallization:** cocoa butter or other plant fats define smoothness and mouthfeel in chocolates and spreads.
- **Fiber interaction:** soluble fibers (pectins) form gels; insoluble fibers provide bulk and chewiness.

These transformations are both physical and chemical, and are carefully controlled during baking, extrusion, or cooling processes.

2.4.3. Nutritional Enhancement

Elaborated products can be fortified or naturally enriched:

- Vitamins and minerals can be added or stabilized using plant-derived compounds.
- Bioactive plant metabolites (polyphenols, carotenoids, dietary fibers) contribute to health benefits.
- Protein quality can be enhanced by combining plant sources (legumes + cereals) for a better amino acid profile.

Enzymatic or chemical transformations during processing can also release or activate certain nutrients, e.g., converting starch to maltose for digestibility, or releasing bound phenolics for antioxidant activity.

 Note : Key Concept

The preservation, texture, flavor, and nutritional quality of elaborated foods result from the synergy between plant biomolecules and industrial processes. Understanding these relationships allows the design of safe, functional, and high-value food products, while fully utilizing the chemical and physical properties of plant-derived compounds

3. Elaborated Cosmetic Products

Cosmetic products are formulations designed to clean, protect, enhance, or beautify the human body, particularly the skin, hair, and nails. Many of these products are derived from plant biomolecules, which provide both functional and active properties. The production of cosmetics follows carefully controlled processing steps to ensure safety, stability, and effectiveness.

3.1. Plant-Derived Biomolecules in Cosmetics

Cosmetic products are designed to clean, protect, and enhance the skin, hair, or nails. Many of these products are derived from plant biomolecules, which provide both functional properties (such as texture, moisture retention, or emulsification) and active properties (such as antioxidant, antimicrobial, or aromatic effects). The production of cosmetics involves careful processing and formulation to ensure safety, stability, and effectiveness.

3.1.1. Main Biomolecules in Cosmetics

Cosmetic formulations utilize a wide range of biomolecules extracted from plants, including:

- Sugars (e.g., glucose, sucrose) for moisturizing and humectant properties
- Starch and polysaccharides as thickeners, stabilizers, and absorbents
- Oils and triglycerides for emollient and protective effects
- Proteins and peptides for repair, regeneration, and conditioning
- Phenolic compounds, flavonoids, and essential oils for antioxidant, antimicrobial, or aromatic properties

These molecules are often modified or combined to optimize performance in creams, shampoos, toothpastes, and perfumes.

3.1.2. Functional Roles of Plant Biomolecules

a) Sugars and polysaccharides

Sugars and polysaccharides, for example, play multiple roles in cosmetic formulations. Sugars act as humectants, attracting and retaining water in the skin and hair, which helps maintain hydration over time. Starches and other polysaccharides serve as thickeners and stabilizers, ensuring smooth, uniform textures in creams and gels.

b) Oils and triglycerides

Oils and triglycerides extracted from plants such as sunflower or jojoba are crucial for emollient and protective effects, forming a thin barrier on the skin to prevent moisture loss and to give the product a pleasant, creamy feel. Proteins and peptides, including wheat and soy proteins, contribute to repair and regeneration by improving elasticity, strength, and overall appearance of hair and skin.

c) plant secondary metabolites

Beyond these, plant secondary metabolites such as phenolic compounds and flavonoids provide antioxidant protection, neutralizing reactive oxygen species generated by UV exposure or environmental pollutants, thereby reducing oxidative stress and premature aging.

d) Essential oils and aromatic compounds

Essential oils and aromatic compounds, such as lavender oil (*Lavandula angustifolia*) or peppermint oil (*Mentha piperita*), contribute not only to fragrance but also to soothing or antimicrobial properties, enhancing the functional value of soaps, perfumes, and skincare products. DHA (dihydroxyacetone), derived from plant sugars, is another example of a plant-based molecule used in self-tanning products, reacting with amino acids in the skin to produce a safe, natural-looking tan.

3.1.3. Cosmetic Formulation and Processing

Cosmetic products require careful formulation to combine active ingredients with excipients, surfactants, and bio-solvents:

- Emulsification: combining water and oil phases with surfactants to create stable creams or lotions
- Solubilization: plant-derived bio-solvents dissolve active ingredients without chemical degradation
- Stabilization: antioxidants prevent oxidation of oils and pigments
- pH adjustment and preservatives: ensure microbial safety and product longevity
- Example of chemical transformation:

In cream formulation, plant oils and lecithins form stable emulsions:

Oil droplets + Emulsifier → Stable oil-in-water emulsion

3.1.4. Examples of Elaborated Cosmetic Products

👉 Example

-
- **Creams and lotions:** moisturize, protect, and deliver active plant compounds
 - **Shampoos and conditioners:** clean, repair, and add shine using proteins and oils
 - **Toothpaste:** starch for texture, plant extracts for antibacterial effects

- **Self-tanning products:** DHA (dihydroxyacetone) derived from plant sugars reacts with amino acids in the skin to produce a natural tan
- **Perfumes:** essential oils provide fragrance and may have protective or soothing effects

4. Elaborated parapharmaceutical Products

4.1. Plant-Derived Biomolecules

Parapharmaceutical products refer to a category of goods situated between food products, cosmetics, and pharmaceuticals, but which do not have a curative or therapeutic status. Their primary objective is to support physiological functions, promote well-being, or contribute to the maintenance of health, without claiming to treat or cure diseases. These products are generally intended for preventive or supportive use and are available without medical prescription.

In contrast to pharmaceutical drugs, parapharmaceutical products are characterized by moderate biological activity, a high safety margin, and a focus on long-term use. They are widely used in health support strategies, particularly those based on plant-derived natural substances.

4.1.1. Plant-Derived Biomolecules

Parapharmaceutical products mainly exploit **secondary metabolites** and functional biomolecules of plant origin, such as polyphenols, flavonoids, carotenoids, phytosterols, saponins, and certain non-toxic alkaloids. These compounds are naturally synthesized by plants and often play protective roles against environmental stress, pathogens, or oxidative damage.

In humans, these biomolecules may exhibit antioxidant, anti-inflammatory, digestive, immunomodulatory, or protective effects, without exerting a direct pharmacological action.

Example

polyphenols from green tea (*Camellia sinensis*) or grape (*Vitis vinifera*) are widely used for their antioxidant properties, while flavonoids from citrus fruits contribute to vascular protection and metabolic balance.

4.1.2. Extraction and Processing of Plant Biomolecules

The production of parapharmaceutical products relies on mild extraction and processing techniques aimed at preserving the integrity and bioactivity of plant compounds. Common methods include aqueous or hydroalcoholic extraction, cold pressing, maceration, and drying techniques such as lyophilization.

Unlike pharmaceutical manufacturing, these processes avoid aggressive chemical modifications. The goal is not to isolate a pure active molecule, but rather to obtain complex extracts or fractions that retain the natural synergy between plant constituents. This approach contributes to both efficacy and safety, which are essential criteria in parapharmacy.

4.1.3. Forms and Formulations of Parapharmaceutical Products

Parapharmaceutical products are formulated in various forms to ensure ease of use, stability, and consumer compliance. Common formulations include capsules, tablets, powders, syrups, herbal teas, and standardized plant extracts. These forms allow controlled intake of bioactive compounds while maintaining flexibility in dosage.

Standardization is an important step in formulation, ensuring that each batch contains a consistent concentration of key biomolecules, even though the product remains non-medicinal. Excipients of plant or mineral origin may be added to improve stability, solubility, or bioavailability, without altering the natural character of the product.

4.1.4. Functional Role and Health Support

Parapharmaceutical products play a supportive role in health maintenance rather than a therapeutic one. Their effects are generally progressive and preventive, contributing to antioxidant defense, digestive comfort, metabolic balance, stress reduction, or immune support.

For instance, dietary supplements rich in plant fibers support intestinal function, while extracts containing phytosterols may help regulate cholesterol absorption. Herbal teas and plant-based syrups are often used for mild digestive or respiratory comfort, illustrating the functional rather than curative nature of parapharmaceutical products.

4.1.5. Position of Parapharmaceutical Products in Bioindustries

From an industrial perspective, parapharmaceutical products represent a growing sector of bioindustries, driven by consumer demand for natural, safe, and sustainable health solutions. They illustrate how plant-derived biomolecules can be transformed into high-value elaborated products, without entering the strict regulatory framework of pharmaceuticals.

This sector highlights the importance of plant biodiversity, controlled processing, and formulation science in developing products that combine natural origin, functional benefits, and industrial feasibility.



Attention

Parapharmaceutical products are not medicines. They are elaborated products derived from plants, designed to support health and well-being through safe, moderate, and non-curative biological activity.

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End-of-Chapter Questions

- What are elaborated products?
- Name three sectors where these products are used.
- What are the main biological components used in these products?
- Which components are important for food products?
- Give one example of a fungal product used in food.
- How are enzymes and microorganisms used in food processing?
- Name one plant-derived component commonly used in cosmetics.
- What is the role of proteins or lipids in cosmetic formulations?
- What are parapharmaceutical products?
- Give an example of a vitamin or enzyme produced by fungi for parapharmaceutical use.
- Why is microbial or fungal production of these compounds economically important?
- Name one industrial process used to produce elaborated products.
- How does fermentation contribute to the production of food or parapharmaceutical compounds?
- Why is the study of raw materials important for high-value product development?

Biotechnology and Technology of Fungi

VI

At the end of this chapter, the learner will be able to understand the role of fungi in biotechnology, analyze different fungal species and processes, and apply this knowledge to exploit fungi for the production of valuable bioproducts.

Fungi play a central role in human life and biotechnology, contributing both directly and indirectly to food, pharmaceuticals, and industrial processes. The use of yeasts in the production of alcoholic beverages and bread is one of the earliest and best-characterized examples of fungal biotechnology. Beyond these classical applications, fungi are consumed directly as edible mushrooms, which provide essential nutrients, and indirectly in products such as blue cheeses, where their unique flavor, aroma, and texture result from fungal metabolic activity.

In addition to food applications, fungi are a rich source of bioactive compounds. For example, the discovery of penicillin from *Penicillium* species marked the beginning of the modern antibiotic era. Fungi are also exploited for the production of enzymes widely used in the food industry, such as amylases, proteases, and lipases, which facilitate starch hydrolysis, protein modification, and lipid processing.

Fungi are highly diverse organisms, broadly classified into two major groups: yeasts, which are unicellular, and molds, which are filamentous. Both groups are extensively used in biotechnology, not only for traditional fermentation processes but also for the production of secondary metabolites, organic acids, biofuels, and nutraceuticals.

The unique metabolic capabilities of fungi, combined with their ability to grow on a wide range of substrates, make them versatile biological tools. Understanding fungal biology, metabolism, and cultivation techniques is therefore essential for exploiting their potential in modern industrial biotechnology. This chapter will provide a comprehensive overview of the technological applications of fungi, highlighting their role in producing products of industrial and pharmaceutical interest.

1. Yeasts and Filamentous Fungi

Fungi exhibit a remarkable diversity in structure, ranging from unicellular yeasts to complex filamentous molds. Understanding their morphology is essential, as cell shape, size, and growth patterns directly influence their physiology, reproduction, and industrial applications. This section provides an overview of the main structural characteristics of yeasts and filamentous fungi and highlights their significance in biotechnology.

1.1. Morphology of Yeasts and Filamentous Fungi

1.1.1. Yeasts

Yeasts are unicellular fungi, primarily belonging to the Ascomycota, Basidiomycota, or Deuteromycota groups. They reproduce mainly through asexual processes, either by budding or fission. Individual yeast cells can vary considerably in size, typically ranging from 2–3 μm up to 20–50 μm in length and 1–10 μm in width, depending on the species and growth conditions (Figure 6.1). A well-known example is *Saccharomyces cerevisiae*, widely used in fermentation and biotechnological applications.

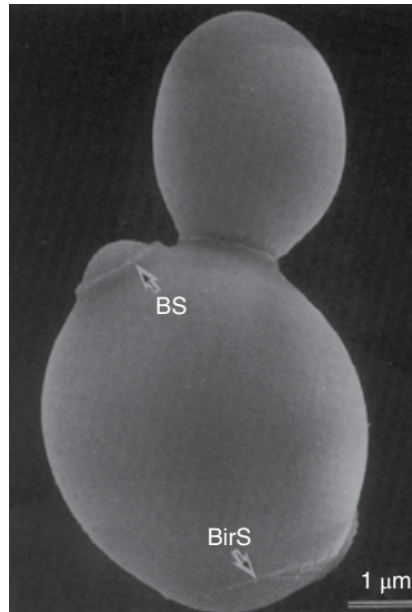


Figure 6.1 Scanning electron micrograph of a typical yeast cell ($\times 10,000$)

1.1.2. Filamentous Fungi (Molds)

Filamentous fungi consist of microscopic, thread-like cells called hyphae. The dense network formed by the hyphae is referred to as mycelium, which supports growth and facilitates nutrient absorption. Filamentous fungi also produce asexual spores, which serve as reproductive units.

These fungi can be cultivated in the laboratory on a variety of solid or liquid media. On agar plates, the colonial growth of mycelium is most apparent, displaying a radial expansion pattern that originates from the inoculum. Hyphae can grow on, within, and sometimes above the substrate, forming a three-dimensional, nearly spherical colony structure (Figure 6.2). Such growth patterns are important for studying fungal physiology, industrial cultivation, and enzyme or metabolite production.

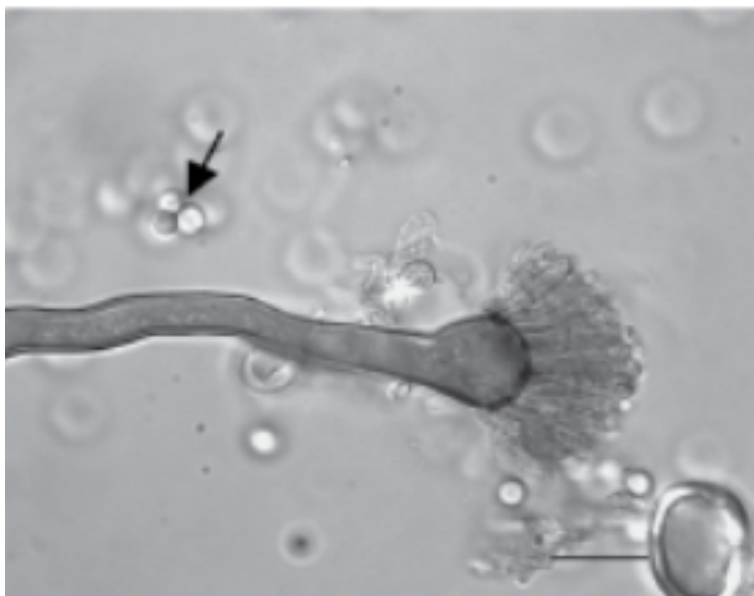


Figure 6.2 Photonic micrograph of filamentous fungus ($\times 100$).

2. Biotechnological applications of fungi

2.1. Agricultural Applications of Fungi

Fungi play a key role in enhancing agricultural productivity, modifying agroecosystems, influencing soil dynamics, and contributing to plant health. Many fungal species establish diverse symbiotic relationships that promote nutrient recycling, restoration of plant metabolites, disease suppression, and overall ecosystem productivity.

Through these interactions, fungi improve soil fertility, enhance plant growth, and support sustainable agricultural practices, making them invaluable tools in agronomic biotechnology and ecosystem management. See Figure 6.3.

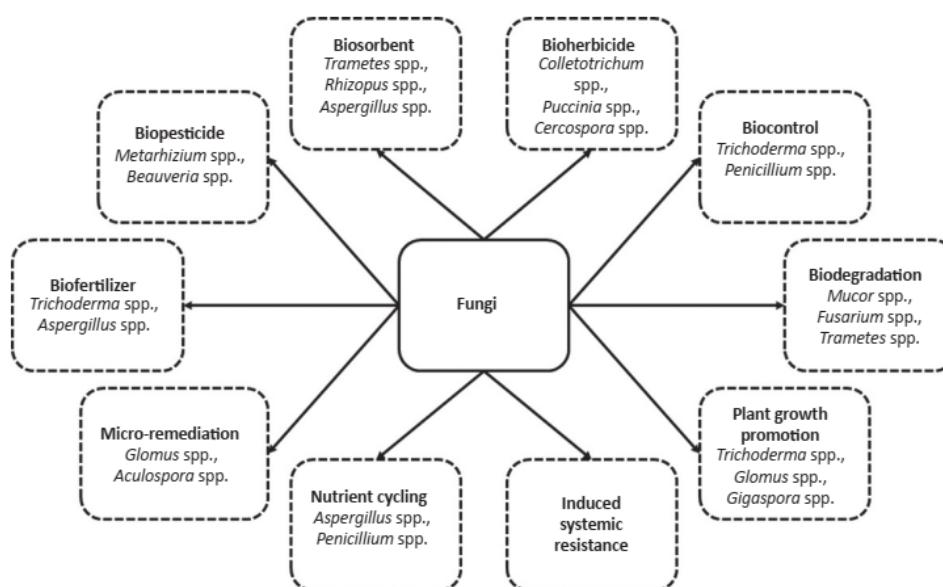


Figure 6.3 The main applications of fungi in sustainable agriculture.

2.1.1. Use of Fungi as Biocontrol Agents

Plant pathogens are a major limiting factor in agricultural productivity. Certain fungi act as biocontrol agents, deploying a variety of defense mechanisms to suppress or eliminate plant pathogens (see Figure 6.4).

Fungal biocontrol mechanisms include:

- Competition for nutrients and space, which limits pathogen colonization.
- Production of antimicrobial compounds, such as antibiotics, enzymes, or secondary metabolites that inhibit pathogen growth.
- Parasitism of pathogens, where the fungus directly attacks harmful microbes.

Induction of plant systemic resistance, stimulating the plant's own defense systems to better resist infection. These strategies make fungi eco-friendly alternatives to chemical pesticides, contributing to sustainable agriculture. The selection of effective fungal strains and understanding their interaction with crops and soil microbiota are critical for maximizing biocontrol efficacy.

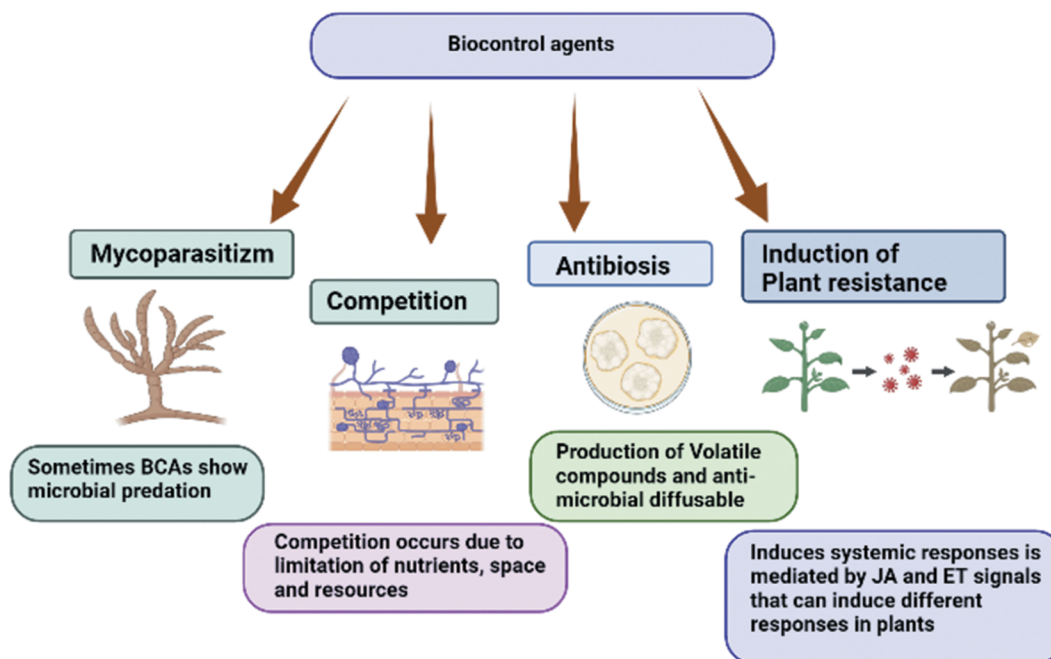


Figure 6.4 Mode of action of biocontrol agents against plant pathogens

2.1.2. Use of Fungal Species as Biofertilizers

Biofertilizers are important alternatives to chemical fertilizers, playing a key role in soil health and sustainable agriculture. Many fungal species form functional associations with various plant parts, establishing mycorrhizal symbioses that enhance nutrient uptake and plant growth.

It is estimated that approximately 80% of terrestrial plants are naturally colonized by mycorrhizal fungi. These associations improve the availability of essential nutrients, particularly phosphorus and nitrogen, and can also enhance plant resistance to environmental stresses and soil-borne pathogens.

Fungal biofertilizers, therefore, not only support sustainable crop production but also contribute to long-term soil fertility, reducing dependence on chemical inputs and promoting eco-friendly agricultural practices.

2.2. Food Applications of Fungi

Fermentation is one of the oldest biotechnological processes, widely used to produce foods with desirable properties and to extend shelf life. Fungi are among the most commonly employed microorganisms in food processing, performing critical roles in flavor, texture, and nutritional enhancement.

Industrial yeasts, primarily from the *Saccharomyces* genus including *S. cerevisiae*, *S. bulderi*, and *Schizosaccharomyces pombe* are essential for the production of bread, alcoholic beverages, and fermented foods.

Filamentous fungi of commercial importance, such as *Aspergillus*, *Penicillium*, and *Ceratocystis*, contribute to the production of enzymes, citric acid, and flavor compounds. These fungi not only facilitate biochemical transformations in food but also provide a foundation for industrial-scale fermentation processes.

2.2.1. Production of Food Enzymes

Enzymes play a crucial role in the food industry, facilitating a wide range of biochemical transformations. The most commonly used enzymes include lipases, pectinases, and proteases, which are applied across various sectors such as dairy processing, brewing, winemaking, juice production, fats and oils processing, and bakery products.

Different fungal species and strains are employed as industrial sources of these enzymes, selected based on their enzymatic activity, stability, and suitability for specific food processes. Table 6.1 summarizes the commonly used fungal strains for enzyme production and their respective applications.

These enzymes enhance product quality, texture, flavor, and shelf life, making fungi indispensable contributors to food biotechnology.

Table 6.1 Sources and applications of industrial enzymes.

Enzymes	Espèce productrice	Utilisation
α -Amylase	<i>Aspergillus niger</i> , <i>A. oryzae</i>	Transformation de l'amidon et industrie agroalimentaire
Chymosin	<i>A. niger</i>	Industrie de transformation de l'amidon
Glucoamylases	<i>A. phoenicis</i> , <i>Rhizopus delemar</i>	Transformation de l'amidon
lipases	<i>A. niger</i> , <i>A. oryzae</i>	Industrie agroalimentaire
Pectine lyases	<i>T. reesei</i>	Industrie agroalimentaire
Protéases	<i>A. niger</i> , <i>A. oryzae</i> , <i>R. delemar</i>	Industrie agroalimentaire
Phytases	<i>A. niger</i> , <i>A. oryzae</i>	Industrie agroalimentaire
Rennin	<i>Mucor miehei</i>	Industrie agroalimentaire
Amyloglucosidase	<i>A. niger</i>	Sirops d'amidon, dextrose
Invertase	Levures spp	Industrie de la confiserie

2.2.2. Production of “Natural” Flavors by Filamentous Fungi

Filamentous fungi, particularly white-rot Basidiomycetes, represent an important group for the production of industrially relevant odorant molecules. Several genera, including *Agaricus*, *Bjerkandera*, *Ischnoderma*, *Pycnoporus*, *Lentinus*, *Phellinus*, and *Trametes*, have demonstrated significant potential in the biosynthesis of flavor compounds such as benzoates, cinnamates, phenylacetates, and butanone derivatives.

These fungi produce flavors through enzymatic transformations of plant-derived precursors, offering a natural alternative to synthetic flavoring agents. Their metabolic versatility and ability to grow on diverse substrates make them valuable tools in the food and fragrance industries, contributing to the development of high-value natural flavor compounds. See Figure 6.5 for vanillin production.

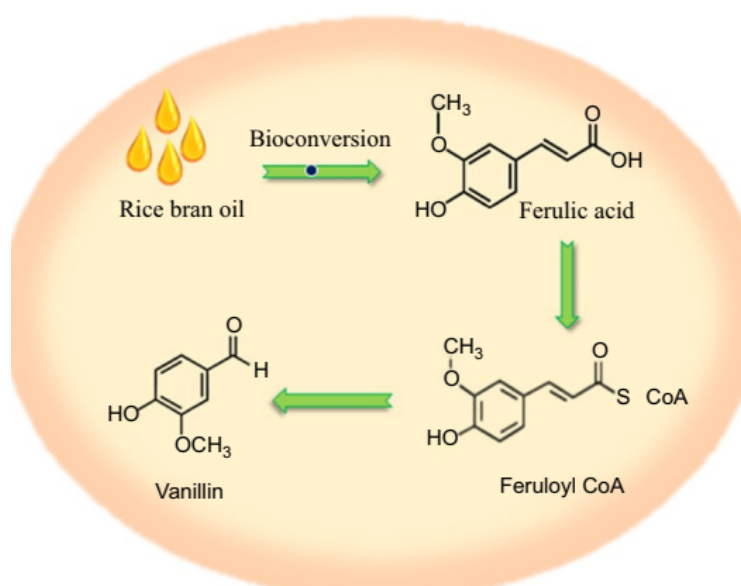


Figure 6.5 Production of vanillin through bioconversion.

2.2.3. Fermented Foods and Beverages

Industrial yeasts play a central role in the production of a wide range of foods and beverages. Fermentation processes involving yeasts are essential for edible products such as cheese and bread, as well as for alcoholic beverages, including beer, wine, and spirits.

Recent advances in biotechnological techniques have enabled the engineering of industrial yeasts, including polyploid strains, which are otherwise difficult to manipulate using traditional genetic approaches. For example, *Kluyveromyces marxianus* can be immobilized on delignified cellulosic material and employed in batch fermentation systems to enhance productivity and process stability.

These innovations allow for improved fermentation efficiency, product consistency, and tailored metabolic profiles, making yeast biotechnology a cornerstone of modern food and beverage production.

2.2.4. Production of Sweeteners by Fermentation

The production of alternative sweeteners using fungi is considered a sustainable approach for numerous industrial applications, as the process can be conducted under controlled conditions, ensuring consistency and quality.

These fungal fermentations provide eco-friendly and scalable alternatives to chemical synthesis, offering advantages such as renewable substrate utilization, reduced environmental impact, and compatibility with food-grade production standards.

The controlled biotechnological production of fungal-derived sweeteners represents a promising strategy for meeting the growing demand for low-calorie and natural sugar substitutes in the food and beverage industry.

Example

Erythritol can be produced by *Trichosporonoides megachiliensis*, while **xylitol** is synthesized using *Yarrowia lipolytica*

2.2.5. Alternative Proteins Produced by Fermentation

Alternative proteins derived from fungi are gaining significant attention as sustainable and nutritious sources of dietary protein. One of the most well-known products on the market is mycoprotein, commercially marketed under the brand name Quorn. Mycoprotein is produced through continuous fermentation of a carefully selected strain of *Fusarium venenatum* (initially known as *F. graminearum*), which is cultivated under controlled conditions to optimize biomass yield, protein content, and texture.

The resulting fungal biomass is high in protein, low in fat, and rich in dietary fiber, making it suitable for a variety of meat alternative products. The production process relies on aerobic fermentation in large bioreactors, where conditions such as pH, temperature, aeration, and nutrient supply are tightly regulated. After fermentation, the biomass is harvested, heat-treated to remove nucleic acids, and processed into textured protein products that mimic the sensory qualities of meat.

Fungal-derived proteins offer several advantages over traditional animal proteins, including reduced environmental impact, lower greenhouse gas emissions, and efficient use of renewable substrates, such as sugars or starches. As the demand for plant-based and sustainable protein alternatives continues to rise, fungal fermentation presents a versatile and scalable platform for producing high-quality proteins for the food industry.

2.3. Medical Applications of Fungi

Fungi are a prolific source of secondary metabolites with significant medical and pharmaceutical applications (see Table 6.2). Many of these compounds have revolutionized modern medicine due to their antimicrobial, immunosuppressive, and cholesterol-lowering properties.

Notable examples include: Antibiotics: Penicillins and cephalosporins, derived from *Penicillium* species, Immunosuppressants: Cyclosporine A, produced by *Tolypocladium inflatum*, is widely used to prevent organ transplant rejection. Cholesterol-lowering agents (statins): Compounds such as lovastatin from *Aspergillus terreus* are used to reduce blood cholesterol levels.

Alkaloids and other bioactive molecules: Fungi also produce diverse alkaloids with antitumor, antiviral, or neuroactive properties.

The production of these medically valuable compounds often involves controlled fermentation processes, where parameters such as substrate composition, pH, temperature, and oxygen supply are optimized to maximize yield and bioactivity.

Fungal secondary metabolites thus represent a versatile and sustainable source of pharmaceutical agents, highlighting the crucial role of fungi in drug discovery and development.

Table 6.2 the main active metabolites (primary and secondary)

	Examples	Production organisms
<i>Primary metabolites</i>		
	Enzymes	<i>Aspergillus</i>
	Industrial alcohol	<i>Saccharomyces cerevisiae</i>
	Organic acids	<i>Aspergillus/Candida</i>
	Fats	<i>Candida</i>
	Polymers	<i>Yarrowia</i>
<i>Secondary metabolites</i>		
	<i>Antibiotics:</i> Penicillin	<i>Penicillium</i>
	Fusidic acid	<i>Fusidium coccineum</i>
	<i>Cholesterol-lowering agents:</i> Lovastatin	<i>Monascus ruber</i>
	Mevastatin	<i>Penicillium citrinum</i>
	<i>Immunosuppressing drugs:</i> Cyclosporin A	<i>Tolypocladium inflatum</i>
	<i>Plant hormones:</i> Gibberellic acid	<i>Gibberella fujikuroi</i>

2.3.1. Production of Antibiotics by Fungi

Among fungal secondary metabolites, antibiotics are the most well-known and extensively studied. These low-molecular-weight compounds are termed antibiotics because, at sub-inhibitory concentrations, they can suppress or inhibit the growth of other microorganisms.

Although several fungal genera are capable of producing antibiotics, only a few are exploited commercially on a large scale, with *Aspergillus* and *Penicillium* being the most important. *Penicillium* species, for example, are renowned for producing penicillins, which revolutionized the treatment of bacterial infections. *Aspergillus* species also produce antibiotic compounds and other bioactive metabolites with pharmaceutical relevance.

The industrial production of fungal antibiotics relies on optimized fermentation processes, where parameters such as medium composition, pH, aeration, and temperature are carefully controlled to maximize yield and biological activity. These processes highlight the importance of fungi as versatile biofactories for medically and commercially significant compounds.

2.3.2. Recombinant Proteins and Vaccines

Fungi and yeasts have become important platforms for the production of recombinant proteins and vaccine components. Several hosts have been successfully exploited for this purpose, including yeasts such as *Saccharomyces cerevisiae* and *Pichia pastoris*, as well as filamentous fungi such as *Aspergillus*, *Penicillium*, and *Neurospora*.

These microbial systems offer several advantages for recombinant protein production, including:

- Rapid growth and scalability in bioreactors.
- Eukaryotic post-translational modifications, which are crucial for the proper folding, glycosylation, and functionality of many therapeutic proteins.
- Safety and cost-effectiveness compared to mammalian cell culture systems.

Recombinant proteins produced by fungal hosts include enzymes, hormones, antibodies, and vaccine antigens, which are widely used in medical, veterinary, and industrial applications. Advances in genetic engineering and fermentation technology continue to expand the potential of fungi as efficient biofactories for high-value biopharmaceuticals.

Example

S. cerevisiae has been successfully employed for the production of several therapeutically important proteins and vaccines, including:

- Hepatitis B surface antigen (HBsAg) – used in recombinant hepatitis B vaccines.
- Insulin – a life-saving hormone for the treatment of diabetes.
- Glucagon – a peptide hormone used in managing severe hypoglycemia.

2.3.3. Cyclosporine A

Immunosuppressive drugs have revolutionized modern organ transplantation by significantly reducing the incidence of graft rejection. One of the most important of these drugs, Cyclosporine A, is produced by the fungus *Tolypocladium inflatum*.

Cyclosporine A functions by inhibiting T-cell activation, thereby preventing the immune system from attacking transplanted organs. Its discovery and industrial production represent a milestone in pharmaceutical biotechnology, highlighting the ability of fungi to serve as biofactories for high-value therapeutic compounds.

Industrial production of Cyclosporine A relies on controlled fungal fermentation, where parameters such as substrate composition, pH, temperature, and aeration are optimized to maximize yield and maintain bioactivity. This process ensures the consistent production of a highly potent and medically essential immunosuppressant.

2.3.4. Statins

Statins are a class of compounds that act as potent competitive inhibitors of 3-hydroxy-3-methylglutaryl-coenzyme A (HMG-CoA) reductase, a key enzyme in cholesterol biosynthesis. By inhibiting this enzyme, statins effectively lower blood cholesterol levels, reducing the risk of cardiovascular diseases.

Several fungi serve as industrial sources of statins:

Lovastatin, produced by *Monascus ruber*, is widely used in the pharmaceutical industry.

Mevastatin, obtained from *Penicillium citrinum*, was among the first statins discovered and helped pave the way for commercial production of cholesterol-lowering drugs.

2.3.5. Alkaloids

Members of the genus *Claviceps*, parasitic fungi that grow on a wide variety of cereal crops, produce numerous secondary metabolites known as alkaloids. These compounds are primarily synthesized within the sclerotia of the fungus.

Alkaloids derived from *Claviceps* exhibit a range of pharmacological activities, many of which target the central nervous system, causing effects such as **hallucinations**, **convulsions**, or vasoconstriction. Certain alkaloids, such as **ergotamine** and **ergotoxine**, have been utilized in medicine for treating migraines, controlling postpartum hemorrhage, and inducing labor, highlighting their therapeutic potential when carefully dosed.

Industrial and biotechnological research focuses on controlled cultivation of *Claviceps* species to produce specific alkaloids, enabling the development of pharmaceutical compounds with consistent activity and safety profiles. These fungal metabolites exemplify the dual nature of bioactive compounds, being both potentially toxic and therapeutically valuable.

2.3.6. Vitamins

Vitamins are essential nutrients required in small amounts, with well-documented and universally accepted importance for human and animal health. Certain fungi have been exploited for the commercial production of vitamins, particularly riboflavin (vitamin B2), which is produced by *Ashbya gossypii* and *Eremothecium ashbyi*.

During the fungal life cycle, the production of specific metabolites can be clearly divided into primary and secondary metabolism phases. Fungal biotechnology has advanced to allow commercial exploitation of these metabolic pathways, enabling the consistent and efficient production of vitamins at an industrial scale.

The economic significance of fungal biotechnology is substantial, given the broad range of valuable products derived from fungi. These include antibiotics, enzymes, vitamins, pharmaceutical compounds, fungicides, plant growth regulators, hormones, and proteins. Harnessing fungal metabolic processes not only ensures a sustainable and cost-effective source of nutrients but also underscores the versatility of fungi as biofactories for high-value biotechnological products.

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End of Chapter Questions

- What is the main difference between yeasts and filamentous fungi?
- Give one example of an industrial yeast and one filamentous fungus.
- How do fungi help control plant diseases?
- What is a biofertilizer, and how do fungi act as one?
- What is a mycorrhizal association?
- Name a food or drink made using yeast fermentation.
- Give one example of a fungal enzyme and its use.
- Which fungi are used to make natural flavors?
- Name one alternative sweetener made by fungi.
- What is mycoprotein, and which fungus produces it?
- What are fungal secondary metabolites?
- Name two fungi used to make antibiotics.
- Which fungus produces Cyclosporine A, and what is it used for?
- What are statins, and which fungi produce them?
- Which fungus produces alkaloids like ergotamine?
- Name a fungus used to make riboflavin (vitamin B2).
- Give an example of a recombinant protein or vaccine made with *S. cerevisiae*.
- What is the difference between primary and secondary metabolism?
- Why are fungi useful for industrial biotechnology?

References list


 VII

- Badal, S., & Delgoda, R. (Eds.). Pharmacognosy: Fundamentals, Applications and Strategies. Academic Press / Elsevier, Amsterdam, 2017. <https://doi.org/10.1016/C2014-0-01794-7>
- Bockisch, M. (1998). The Extraction of Vegetable Oils. In *Fats and Oils Handbook* (pp. 345–445). AOCS Press / Elsevier. <https://doi.org/10.1016/B978-0-9818936-0-0.50010-X>
- Cereda, M. P., & Vilpoux, O. F. (Eds.). 2022. *Starchy Crops Morphology, Extraction, Properties and Applications: Vol. 1: Underground Starchy Crops of South American Origin: Production, Processing, Utilization and Economic Perspectives*. Elsevier / Academic Press. ISBN 978-0-323-903509; <https://doi.org/10.1016/C2020-0-02222-X>
- Featherstone, S. (Ed.). *A Complete Course in Canning and Related Processes: Volume 1 – Fundamental Information on Canning*. Elsevier, Oxford, 2015. <https://doi.org/10.1016/C2013-0-16338-6>
- Galanakis, C. M. (Ed.). *Lipids and Edible Oils: Properties, Processing and Applications*. Academic Press, Elsevier, Oxford, 2020. <https://doi.org/10.1016/C2018-0-01919-2>
- Grumezescu, A. M., & Holban, A. M. (Eds.). *Food Bioconversion (Handbook of Food Bioengineering, Vol. 2)*. Academic Press, Elsevier, London, 2017. ISBN 978-0-12-811413-1.
- Jaison, J. P., Kurian, J. T., Scaria, S. S., Gangwar, J., & Sebastian, J. K. (2024). Bioactive Compounds and Biological Activities of Arrowroot (*Maranta arundinacea* L.). In *Reference Series in Phytochemistry* (pp. 523–540). Springer Nature. https://doi.org/10.1007/978-3-031-44746-4_25
- Jamalimoghadam, M., & Saffarzadeh, A. (2021). Sustainable Alkali-Activated Materials. In F. Colangelo (Ed.), *Handbook of Sustainable Concrete and Industrial Waste Management: Recycled and Artificial Aggregate, Innovative Eco-Friendly Binders and Life Cycle Assessment*. Woodhead Publishing / Elsevier Science & Technology. <https://doi.org/10.1016/C2019-0-04591-8>
- Kringel, D. H., Guerra Dias, A. R., da Rosa Zavareze, E., & Gandra, E. A. Fruit Wastes as Promising Sources of Starch: Extraction, Properties and Applications. *Starch – Stärke*, 72(3-4), 1900200, 2019. <https://doi.org/10.1002/star.201900200>
- Kumar, M., Tomar, M., Potkule, J., Verma, R., Bhoite, A. G., & others. (2021). Advances in the plant protein extraction: Mechanism and recommendations. *Food Hydrocolloids*, 115, Article 106595. <https://doi.org/10.1016/j.foodhyd.2021.106595>
- Misra, V., Srivastava, S., & Mall, A. K. (Eds.). *Sugar Beet Cultivation, Management and Processing*. Springer Singapore, 2022. ISBN 978-981-19-2730-0. <https://doi.org/10.1007/978-981-19-2730-0>
- Ötleş, S., & Özyurt, V. H. (2021). Biotransformation in the production of secondary metabolites. In Atta-ur-Rahman (Ed.), *Studies in Natural Products Chemistry, Volume 68: Bioactive Natural Products* (pp. 435–457). Elsevier Science & Technology. <https://doi.org/10.1016/B978-0-12-819485-0.00007-4>

Rasmussen, S., & Auerbach, G. (Eds.). *Fungal Biotechnology and Bioengineering*. Springer Singapore, 2023. ISBN 978-981-97-8808-8. <https://doi.org/10.1007/978-981-97-8808-8>.

Santos, F., Borém, A., & Caldas, C. (Eds.). *Sugarcane: Agricultural Production, Bioenergy and Ethanol*. Academic Press / Elsevier, Oxford, 2015. <https://doi.org/10.1016/C2014-0-02692-5>

Sapuan, S. M., Ismail, H., & Zainudin, E. S. (Eds.). *Natural Fiber Reinforced Vinyl Ester and Vinyl Polymer Composites: Development, Characterization and Applications*. Woodhead Publishing, Elsevier Science & Technology, Cambridge / Amsterdam, 2018. ISBN 978-0-08-102160-6. <https://doi.org/10.1016/C2016-0-03362-4>

Sharma, A. K., & Sharma, A. (Eds.). *Plant Secondary Metabolites: Physico-Chemical Properties and Therapeutic Applications*. Springer Singapore, 2022. ISBN 978-981-16-4779-6. <https://doi.org/10.1007/978-981-16-4779-6>

Silvio, L. D. (Ed.). *Tribology of Natural Fiber Polymer Composites*. Woodhead Publishing Ltd, Cambridge, UK, 2008. ISBN 978-1-84569-393-0.

Wermuth, C. G. (Ed.). *The Practice of Medicinal Chemistry* (2nd ed.). Academic Press, Elsevier, San Diego / London, 2003. <https://doi.org/10.1016/B978-0-12-7444481-9.X5000-4>