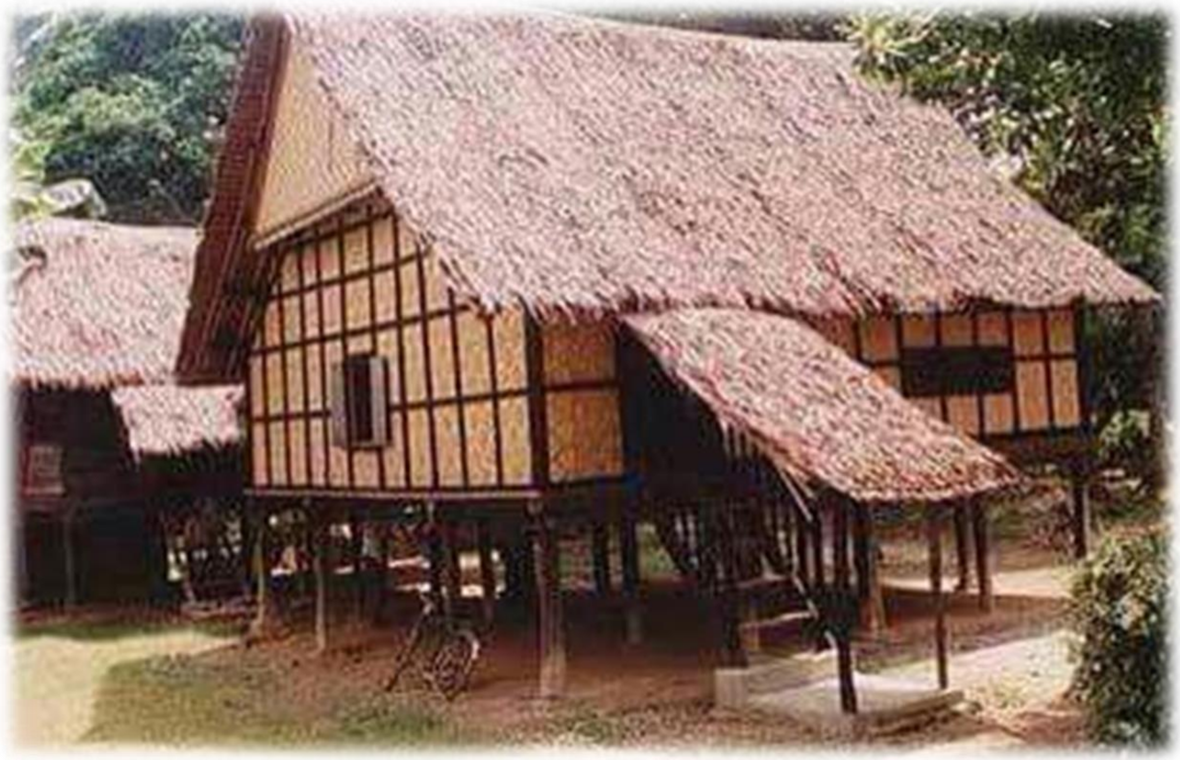
Binding and construction materials: Plant Fibre Retting

Dad: why doesn't everyone build their house with wood and leaves like us? It is so much more sustainable!



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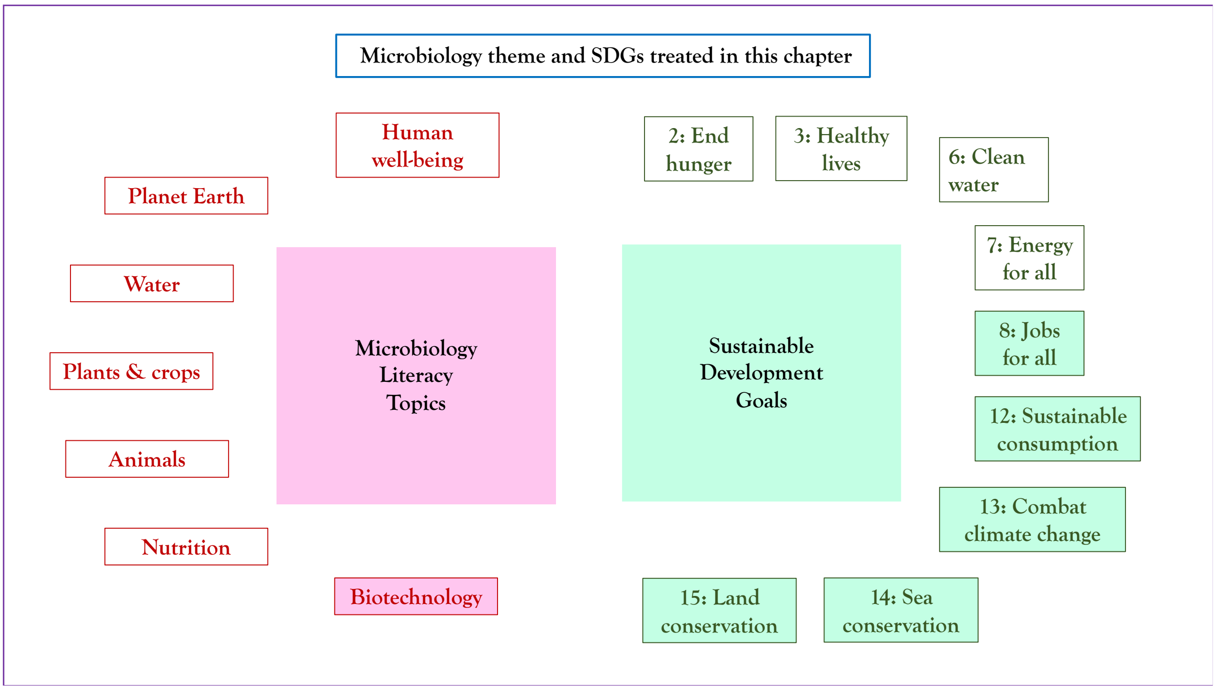
Binding and construction materials: Plant Fibre Retting

Storyline

Before plant fibres are used in such applications, the process of retting is usually employed to separate fibre bundles from other plant material. Retting is a biological process, involving microbial secreted enzymes to remove non-cellulosic materials attached to the fibre bundle, and yielding detached cellulosic fibres. The use of the plant fibres helps meet many of Sustainable Development Goals (SDGs).

The Microbiology and Societal Context

The microbiology: retting; renewable sources; degradable sources; greenhouse gas reduction. *Sustainability issues:* Environmental and economic impact; reduce freshwater usage, climate change combat.



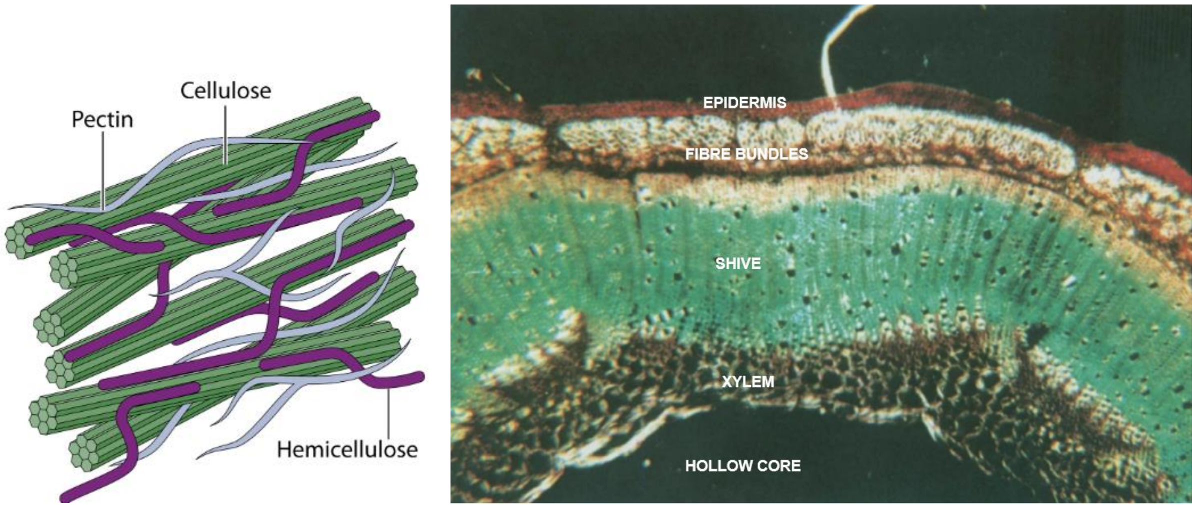
Retting: the Microbiology

1. ***Plant fibres have been used for many purposes since pre-historic times.*** The oldest fabric fibers ever discovered, which were found in simple woven clothing made from flax, are nearly 36,000 years old. These fibers are a predecessor of linen, the oldest woven natural fabric. Besides that, plant fibres have been employed since the reign of the Pharaohs when straw was put into bricks. Dried palm leaves were also used as roofing material to help shed rainwater, keep heat away from the house, and provide good ventilation. Such inventions were important milestones in the development of civilization.

2. ***Plant Fibres.*** Natural fibres are organic compounds consisting of cellulose, hemicellulose, lignin and various minor constituents. They are responsible for providing the plant with its form and strength, and in the case of trees, their woodiness. The fibres are bound together with the epidermis, shives, woody core, and xylem to form stems and branches. The

epidermis is the plant skin and protects internal cells and tissues, and prevents moisture evaporation, while xylem, the woody core, and shives help to transfer water and nutrients from roots to the whole plant. The fibres located in the phloem appear as bundles and provide strength and stiffness to the plant.

In order to obtain the natural fibres free of other plant material, the pectin and lignin constituents that glue the fibres together must be removed. The goal of retting process is to remove these gluing components and release the fibres from bundle attachment.



Plant stem structure. Left: diagrammatic; Right: as seen by electron microscopy

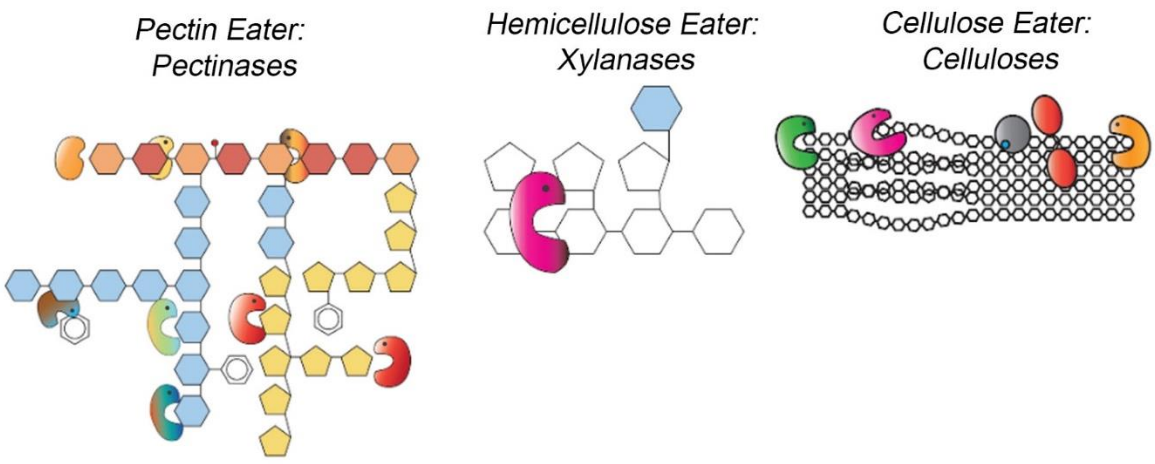
3. ***Retting.*** Retting is the microbiological process of removing non-cellulosic materials attached on the fibre bundle by enzymatic activities, to yield detached natural fibres. There are two basic retting processes: water retting and dew retting.

Water retting is carried out by submerging bundles of stalks in still or slow-moving waters and involves fermentation by anaerobic bacteria, principally *Clostridium sp.*, that rets bast fibres by producing enzymes that hydrolyze fibre-binding components. However, the anaerobic fermentation results in severe water pollution, contaminated wastewater, and a putrid odor

Dew retting is employed in areas with limited water resources but with heavy night time dews, and involves fungi. Dew retting takes a very long time to complete the process.

Water retting (left) and Dew retting (right) of natural fibres.

More recently, retting by isolated enzymes – cellulases, xylanases and pectinases – was introduced as a potential alternative retting method. The customized enzymes produce premium quality retted natural fibres.



The microbial secreted enzymes used to break down fibre binding components

4. ***Different types of fibre are obtained from different plant materials and are used for different purposes.*** Natural plant fibres are obtained from various parts of plants. The fibres are mainly classified as seed fibres (e.g., from cotton and kapok), stem or bast fibres (e.g., from flax, jute, hemp, Kenaf, and sugarcane), and leaf fibres (e.g., from pineapple, banana).

Bast fibres are soft woody fibres obtained from the stems of dicotyledonous plants (flowering plants with net-veined leaves). The bast fibres, usually characterized by fineness and flexibility, are also known as "soft" fibres, distinguishing them from the coarser, less flexible fibres of the leaf fibre, or "hard" fibre, group.

Leaf fibres are hard, coarse fibres obtained from leaves of monocotyledonous plants (flowering plants that usually have parallel-veined leaves, such as grasses, lilies, orchids, and palms.

Most bast fibres are quite strong and are widely used in the manufacture of ropes and twines, bagging materials, and heavy-duty industrial fabrics. In the early 21st century, jute was used mainly for sacking and wrapping purposes. Leaf fibres are chiefly employed for such cordage as rope and twine. They may also be used for woven fabrics, and for this purpose do not usually require spinning.

5. Natural fibres are renewable, biodegradable, environmentally friendly and sustainable. The use of natural fibres has to a large extent been replaced by synthetic fibres derived from petrochemicals – just think of your drip-dry blouse or shirt, or the string you use to tie up a parcel containing a present. But many synthetic materials are very poorly degradable, so are bad for the environment, and run counter to the philosophy of a circular economy. They are also made from non-renewable starting materials, so are not sustainable. In contrast, natural fibres are renewable, biodegradable and sustainable. It is time to return to products made with natural fibres!

6. ***Natural fibre-reinforcement of plastic is a sustainable process with renewable material having almost zero cost.*** Today, many objects you see on a daily basis, such as car dashboards, furniture, aircraft interiors and wood-like floorings, are made of plastics. Plastics are used to reduce weight and for ease of production. Yet, for some of these products, fibre-reinforced plastic is the more accurate term because fibres are incorporated into the plastic to improve its properties.

Various types of natural fibres.

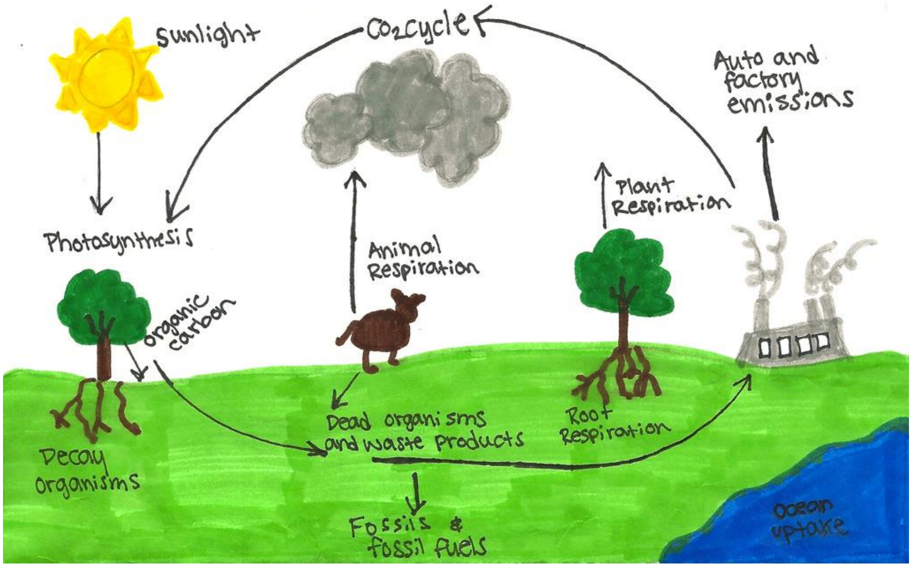
Synthetic fibres were once the popular choice for incorporation into strong/durable plastic products. However, numerous human health and environmental issues were found to be associated with these synthetic fibres, which prompted the exploration of alternative options. Natural fibres are byproducts of agricultural/plantation operations. These have almost zero cost because otherwise these byproducts end up being buried or burned. Currently, more than 32 million metric tons of natural fibres are produced annually.

7. ***Natural fibres accelerate microbial digestion of plastic wastes.*** Plastic wastes that are not handled in the proper manner may eventually end up in the ocean, which they pollute and harm marine life. Even correct handling includes burying plastic wastes in landfills, which are increasingly occupying valuable diminishing land surface and in which they can persist for decades. The incorporation of natural fibres in the plastic products could accelerate biodegradability, because they themselves are biodegradable and attract microbial colonization.

8. ***The very advantages of natural fibres also constitute disadvantages.*** The hydrophilic nature of natural fibres attracts water and moisture, which promotes their colonization by microbes and degradation. The very advantage of their biodegradability after disposal can be a disadvantage when they are in use, requiring extra care to keep them dry.

Furthermore, every batch of natural fibres may perform slightly differently, even using the same fibre retting method. This is because of natural variation in the structure of the natural fibres, which is affected by plantation geometry, climate and handling.

Nevertheless, the use of natural fibres helps us fight plastic waste accumulation and global warming. The plantation produces plants that through photosynthesis extract carbon dioxide from the air and sequester it. Natural fibre is a good friend of us and mother nature. We must learn to love it and use increasingly instead of synthetic fibre!



Carbon cycle in nature

Relevance for Sustainable Development Goals and Grand Challenges

Natural fibre production by microbial retting is related to several SDGs.

- **Goal 8. Work for all.** Retting is a process that provides employment in low-to-middle income countries. The expected growth in demand for natural fibres will stimulate growth in retting-associated employment, although this may tend to occur at a more industrial level.
- **12. Sustainable production and consumption.** On one hand, retting and the use of natural fibres contribute to sustainable production and consumption, in that they replace plastics and the linear economy associated with plastics, and utilize renewables. On the other hand, the process of retting creates a wastewater characterized by brownish-yellow color, bad odor and high organic content of lignin, cellulose and hemicelluloses, that needs to be treated before it can be reused.
- **Goal 13. Combat climate change.** The production and incineration of plastics releases tons of greenhouse gases. The production of natural fibres through plant photosynthesis removes and sequesters the greenhouse gas carbon dioxide. Moreover, the biodegradation of natural fibre products after use creates microbial biomass that contributes to soil carbon, which also represents a reduction in greenhouse gas production.
- **Goal 14. Conserve the oceans.** The use of natural fibres in products endows them with partial or total biodegradability, so they are less polluting for the oceans. Importantly, as alternative products to plastic, use of natural fibre products will reduce plastic pollution of the oceans.
- **Goal 15. Sustainable use of terrestrial ecosystems.** The use of natural fibres in products endows them with partial or total biodegradability. This reduces the pressure on landfill sites for municipal solid wastes created by plastics and products made from synthetic fibres.

Potential Implications for Decisions

1. ***Individual***
    a. shall I buy a blouse or shirt made from synthetic or natural fibre?
    b. shall I use a plastic or natural fibre grocery bag when I go shopping?

2. ***Community policies***
    a. Use local walkways and empty public spaces to plant suitable plants. This improves air quality in your greener living area.
    b. Create new green areas for public use.
    c. Encourage use of the leaves/stems from public plants for retting by skilled workers to generate additional incomes for community.

3. ***National policies***
    a. Provide funding for research and development
    b. Provide incentives for natural fibre plantation farmers.
    c. Promote the use of natural fibres in commercial products

Pupil Participation

1. ***Class discussion of the benefits associated with natural fibre plantations***
    a. Impact on the environment.
    b. Impact on neighboring societies.
    c. Class discussion of natural fibre substitution in our daily applications.

2. ***Pupil stakeholder awareness***

a. Microbes accomplish retting of natural fibres. Can you think of anything that might be done to advance any of the SDGs?

b. Can you think of anything that might be done to promote the usage of natural fibres in your neighborhood and nation?

c. Can you think of anything you might personally do to reduce global warming?

3. ***Exercises***

a. Natural fibre plant selections normally depend on climate. Which plant is more preferable in your local area?

b. Microbial retting of fibre requires specialist knowledge. What can stakeholders do to deliver such knowledge to the right persons?

c. To contribute to the SDGs, companies need to take responsibility for using green materials like natural fibres to replace or partially replace synthetic non-degradable materials. However, they experience difficulty doing this. Can you suggest any solutions?

The Evidence Base, Further Reading and Teaching Aids

Natural fibre Retting

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Glossary

Anaerobic: Living, active, occurring, or existing in the absence of free oxygen; anaerobic respiration; anaerobic bacteria

Biodegradability: The capacity for biological degradation of organic materials by living organisms down to basic substances such as water, carbon dioxide, methane, basic elements and biomass

Carbon Sequestration: A natural or artificial process by which carbon dioxide is removed from the atmosphere and held in solid or liquid form.

Cellulose: A molecule, consisting of hundreds – and sometimes even thousands – of carbon, hydrogen and oxygen atoms. Cellulose is the main substance in the walls of plant cells, helping plants to remain stiff and upright.

Cellulosic Fibre: Fibers made with ethers or esters of cellulose, which can be obtained from the bark, wood or leaves of plants, or from other plant-based material.

***Clostridium* sp:** A genus of Gram-positive bacteria. The family contains around 250 species that include common free-living bacteria, as well as important pathogens.

Dew Retting: The harvested plant stalks are spread evenly in grassy fields, where the combined action of bacteria, sun, air, and dew produces fermentation, dissolving much of the stem material surrounding the fibre bundles. Within two to three weeks, depending upon climatic conditions, the fibre can be separated.

Dicotyledonous plants: One of the two groups into which all the flowering plants are classified where its seed has two embryonic leaves or cotyledons.

Enzyme: A protein produced by a living organism that helps a chemical change happen or happen more quickly, without being changed itself.

Epidermis: The outermost of the three layers that comprise the wood skin. It provides a barrier

to infection from environmental pathogens and regulates the amount of water released from the body into the atmosphere through transepidermal water loss.
Fermentation: A metabolic process that produces chemical changes in organic substrates through the action of enzymes.
Fibre bundle: A batch of plant fibres held together with gluing components.
Hemicellulose: One of a number of heteropolymers (matrix polysaccharides), such as arabinoxylans, present along with cellulose in almost all terrestrial plant cell walls
Hydrophilic: Tending to be attracted to water or to easily dissolve in, mix with, absorb, or be saturated by water.
Hydrolyze: The process of breaking water (or H_2O) into two parts: a positive hydrogen, H^+, and a negative hydroxyl, $(OH)^-$.
Incubation: The process of producing microbes in a controlled medium.
Lignin: A class of complex organic polymers that form key structural materials in the support tissues of most plants. Lignins are particularly important in the formation of cell walls, especially in wood and bark, because they lend rigidity and do not rot easily. Chemically, lignins are polymers made by cross-linking phenolic precursors.
Pectinase: It is a group of enzymes that catalyzes the degradation of pectic substances, either by depolymerization (hydrolases and lyases) or de-esterification (esterases) reactions.
Phloem: Living tissue in vascular plants that transports the soluble organic compounds made during photosynthesis and known as photosynthates, in particular the sugar sucrose, to parts of the plant where needed. This transport process is called translocation.
Photosynthesis: The process by which plants use sunlight, water, and carbon dioxide to create sugars that provide the organism with organic carbon and energy.
Plant Fibre: Generally composed of cellulose, often in combination with other components such as lignin
Methane gas: A hydrocarbon that is a primary component of natural gas. Methane is also a greenhouse gas (GHG), so its presence in the atmosphere affects the earth's temperature and climate system
Microplastic: Extremely small pieces of plastic in the environment that come from consumer products and industrial waste.
Monocotyledonous plants: Referred to as monocots where the seeds produced typically contain only one embryonic leaf or cotyledon.
Natural Fibre: Fibers that are produced by geological processes, or from the bodies of plants or animals.
Natural Fibre Reinforced Plastic: Composite materials, in which at least the reinforcing fibres are derived from renewable and carbon dioxide neutral resources such as wood or plants.
Shives: Consist of "the woody inner portion of the hemp stalk, broken into pieces and separated from the fiber in the processes of breaking and scutching" and "correspond to the shives in flax, but are coarser and usually softer in texture". Shives have traditionally been a by-product of fiber production
Synthetic Fibre: Fibers made by humans through chemical synthesis, as opposed to natural fibers that are directly derived from living organisms, such as plants (like cotton) or fur from animals.
Xylanases: Hydrolytic enzymes which randomly cleave the β-1,4 backbone of the complex plant cell wall polysaccharide xylan. Diverse forms of these enzymes exist, displaying varying folds, mechanisms of action, substrate specificities, hydrolytic activities (yields, rates and products) and physicochemical characteristics
Xylem: Transports water from roots to stems and leaves, but also nutrients
Water Retting: In the most widely practiced method, bundles of stalks are submerged in water.

The water, penetrating to the central stalk portion, swells the inner cells, bursting the outermost layer, thus increasing absorption of both moisture and decay-producing bacteria.