1 Horticulture – Whole Plant Integration of Many Disciplines

Horticulture is a unique combination of art and science. Students from many disciplines blend math, science and art skills to enrich our world. The design and aesthetics of horticulture rely on artistic abilities while understanding plant function requires a strong science and math background.

A basic understanding of plant anatomy and physiology are acquired by studying botany and its allied disciplines. In order to understand the complex nature of plant physiology, strong foundations in chemistry and biochemistry are needed. Environmental influences of light and temperature on plant growth, development and productivity are readily comprehended with an appreciation of the physics involved.

Most students specialize in one of the five major branches of horticulture: (i) pomology; (ii) olericulture; (iii) floriculture; (iv) ornamental, nursery and landscape plants; and (v) landscape architecture (Fig. 1.1).

Pomology is the study of fruit production and is usually subdivided into tree and small or bush fruits. The major tree fruit crops normally include almond (*Prunus dulcis*), apples (*Malus domestica*), apricots (*Prunus armeniaca*), banana and plantains (*Musa* spp.), cacao (*Theobroma cacao*), cashew (*Anacardium occidentale*), cherries (*Prunus avium, Prunus cerasus*), citrus (*Citrus* spp.), coconut (*Cocos nucifera*), coffee (*Coffea arabica, Coffea canephora*), date (*Phoenix dactylifera*), hazelnut (*Corylus avellana*), macadamia (*Macadamia integrifolia, Macadamia tetraphylla*), mango (*Mangifera indica*), oil palm (*Elaeis guineensis*), olive (*Olea europaea*), papaya (*Carica papaya*), peaches and nectarines (*Prunus persica*), pear (*Pyrus communis, Pyrus pyrifolia*), pecan (*Carya illinoensis*), pistachio (*Pistacia vera*), plums (*Prunus domestica, Prunus salicina*) and walnut (*Juglans* spp.). The small, or bush fruit, include blackberries (*Rubus* spp.), blueberries (*Vaccinium* spp.), cranberries (*Vaccinium macrocarpon*), currants (*Ribes* spp.), gooseberries (*Ribes* spp.), grapes (*Vitis* spp.), kiwifruit (*Actinidia* spp.), raspberries (*Rubus* spp.) and strawberries (*Fragaria* × *ananassa*). Fruit crops may also divided into region of adaptation, namely temperate, subtropical and tropical. Most fruit crops are perennial or biennial although strawberries may be grown as an annual in many regions of the world. Most fruit is field grown, with the notable exception of greenhouse-produced strawberries and raspberries. Small fruit culture is ideally suited for protected culture using high tunnels.

Olericulture is the study of vegetable production. Most vegetable crops are annuals, although there are some perennials, such as asparagus (*Asparagus officinalis*). Some vegetables such as beets (*Beta vulgaris*), carrots (*Daucus carota*) and cabbage (*Brassica oleracea*) are botanically biennial, but are grown and harvested as annuals. Most vegetable production is field oriented. Tomatoes (*Solanum lycopersicum*) and peppers (*Capsicum annuum*) are notable exceptions to this, and many crops are forced early or grown under a lengthened season through the use of unheated tunnels.

Floriculture is the study of flower production, either in the field or in greenhouses.

The study of ornamental, nursery and landscape plants makes up the fourth branch of horticulture. This branch is often intimately linked to landscape architecture since the plants involved in this branch are the materials used in the landscape.

The study of landscape design and implementation is collectively known as landscape architecture. Landscape architects not only have to know how to integrate plant materials into our surroundings, but also, which ones are most suitable for specific sites.

Plant Anatomy Review

A plant's function is intimately linked to its structure. In order to understand how an organism works, we

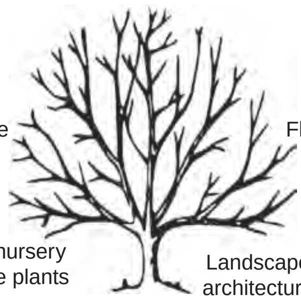

Fig. 1.1. The major branches of horticulture.

dissect it and study its individual pieces. How do we know what we know? We study the structures in plants using either light or electron microscopes and we study the functions of the various parts using experiments involving cell parts, whole cells, tissues or whole plants. Students are referred to *Esau's Plant Anatomy* by Evert and Eichorn (2006), who re-wrote Katherine Esau's classic text, if they are in need of more than a review or would like to see illustrations of many of the cellular components.

Plant Parts

Cells and their parts

The basic building block of all living organisms is the cell. Each individual structure in the cell plays a unique role in the overall function of the cell (Table 1.1). The integration of these individual parts into a living cell is one of the wonders of biology. There are many cell types, shapes and sizes. To gain a perspective on just how small an individual cell is, consider that 150,000,000 typical plant cells would fit into a space approximately 3 cm^3.

The cell wall

If we looked at one individual plant cell and worked our way inward, we would first observe the outer box-like structure called the cell wall. This structure is unique to plants; animals do not have cell walls. This 'box' is made up of cellulose fibers (long molecules of glucose attached to each other in a way that humans cannot digest) glued together with carbohydrate-based substances known as lignins and pectins. The cellulose in the cell wall is what we often refer to as roughage or fiber. (Cellulose is insoluble fiber, important in maintaining intestinal regularity. The other type of fiber, soluble fiber, has important health benefits that will be discussed in Chapter 17, this volume.)

The cell wall is important for giving plants their rigidity and structure. By being rather rigid, cell walls allow pressure to build up within the cell itself. This pressure, called turgor pressure, is responsible for the upright nature of most plants. When water

Table 1.1. The major parts and functions of a typical plant cell.

Cell component	Function(s)
Cell wall	Contains the rest of the cell Allows build up of turgor pressure
Plasmalemma	Encloses the living entities of the cell Selectively permeable to regulate influx and efflux from protoplasm
Plasmodesmata	Connects adjacent cells to allow intercellular communication
Nucleus	Stores the genetic material for cell structure and function in the form of DNA
Ribosome	Responsible for protein synthesis
Endoplasmic reticulum	Location of many ribosomes Important in membrane and lipid synthesis
Vacuole	Contains many products of cellular metabolism Important in regulating cellular turgidity
Plastids	Synthesis and/or storage of cellular products Photosynthesis
Leucoplast	Monoterpene synthesis
Chromoplast	Store pigments
Elaioplasts	Store lipids
Proteinoplast/aleuronoplasts	Store protein
Amyloplast	Store starch Important in geotropism
Chloroplast	Photosynthesis
Golgi bodies	Production of cell wall materials
Mitochondria	Respiration

is lacking, turgor pressure often decreases, which reduces the plants' rigidity causing them to wilt.

The cell wall is the non-living part of the cell. It is the container in which the living parts of the cell, the plasmalemma and all components contained therein, are enclosed.

The plasmalemma

The plasmalemma is a double-layered membrane containing all the cell parts interior to the cell wall. Think of it as a 'bag' of water and dissolved substances in which all the other cell parts reside. Each cell part has a unique function, and when they are all integrated, that creates the living cell. The plasmalemma selectively regulates what moves into and out of a cell.

In addition to its regulatory function, the plasmalemma allows pressure to build up due to turgor. Think of the plasmalemma as a balloon. Only a certain amount of pressure could build up in the 'balloon' before it would burst if there was not a 'box' containing it. Thus it is the combination of pressure build up inside the plasmalemma and the resistance to that pressure afforded by the cell wall which gives plants their rigid nature.

The plasmalemma is selectively permeable due to its structure. It is essentially two sheets of lipids floating against each other. These lipids are hydrophobic, thus they keep water and anything dissolved in water either inside or outside the cell. Embedded across these two sheets of lipids, are proteins. Proteins are hydrophyllic, thus they allow water and solutes to move through them and into or out of the cell. Of course the solute molecules have to be small enough to fit through the spaces within the protein structure to move in either direction. Movement of molecules may also be regulated by concentration and electrical charge gradients across the membrane.

The plasmalemma together with everything inside it is called the protoplast. Thus your typical plant cell consists of a protoplast surrounded by a cell wall.

The plasmodesmata

There are numerous outgrowths of the plasmalemma which connect adjacent cells to each other. These membrane outgrowths are called plasmodesmata. The plasmodesmata allow for communication between cells via movement of substances from one cell to another. This movement may be due to normal cellular processes or it might be triggered by some environmental stimulus.

The protoplasm

We call the watery liquid inside the plasmalemma which contains the other cell parts the protoplasm. It is a mixture of water and dissolved substances including sugars, proteins, and salts. If we wish to refer to the watery liquid inside the plasmalemma but outside the nucleus, we would call it the cytoplasm. The liquid inside the nucleus is the nucleoplasm. Thus the nucleoplasm plus the cytoplasm is collectively the protoplasm.

Organelles

Organelles are individual membrane-bound components of the cell. Each organelle has its own membrane. Some organelles synthesize while others catabolize substances. Thus the membranes help to compartmentalize the cell preventing metabolic chaos.

THE NUCLEUS The nucleus is a membrane-bound organelle in which the genetic material for cell structure and function is stored in the form of deoxyribonucleic acid or DNA. This DNA stores the code for proteins, of which many are enzymes, and these enzymes run the cellular show. Normally, the DNA is not visible under a microscope. During cell division, the DNA becomes visible as chromosomes.

The membrane surrounding the nucleus is called the nuclear membrane. During normal cellular activity, the message coded in DNA is translated into ribonucleic acid or RNA. The RNA codes for specific sequences of amino acids which ultimately give rise to proteins and then enzymes outside of the nucleus at the ribosome. The particular sequence of amino acids imparts structure to the enzymes and the structure ultimately imparts a function.

RIBOSOMES AND THE ENDOPLASMIC RETICULUM Ribosomes are responsible for protein synthesis. Ribosomes may be free-floating in the cytoplasm or may be attached to a long string-like membrane called the endoplasmic reticulum, which is also found in the cytoplasm.

THE VACUOLE The organelle which often occupies the greatest amount of cellular space is the vacuole. The vacuole is a large, membrane-bound organelle full of many products of cellular metabolism. The membrane of the vacuole is called the tonoplast. Since it contains many water-soluble components, the vacuole is important in cellular turgidity and water relations of plants. In fact, it is the vacuole which imparts the greatest influence on turgidity in the cell.

PLASTIDS Plastids are small, membrane-bound organelles whose primary function is storage of specific cellular products. Their name reflects their content. Leucoplasts are colorless plastids that primarily synthesize monoterpenes. Elaioplasts store lipids and proteinoplasts (aleuronoplasts) store proteins. Chromoplasts are plastids containing pigments and are often found in flower petals and fruit. Amyloplasts are plastids containing starch and are often found in root cells or immature starchy fruit. Amyloplasts are responsible for geotropic responses.

Chloroplasts are green plastids containing the pigment chlorophyll. Chloroplasts are the site of photosynthesis and are particularly abundant in leaves. Two important types of chlorophyll, 'a' and 'b' trap light energy and that energy is ultimately stored (often as a carbohydrate, fat or protein) in the plant or used for metabolism. Chloroplasts contain their own DNA and reproduce on their own. There may be from one to more than 100 chloroplasts in a cell.

There are two membranes surrounding the chloroplast, an inner and an outer chloroplast envelope. Another membrane inside the chloroplast has flat vesicles called thylakoids. These thylakoids are stacked in pancake-like structures called grana. The grana provide a large surface area for maximum light interception. The membrane that forms the thylakoid is called the lamella and the liquid in which grana reside is called the stroma.

GOLGI BODIES Golgi bodies are organelles that are responsible for the production of materials used in cell wall construction.

MITOCHONDRIA The mitochondria are the organelles responsible for the controlled release of energy (respiration) from food within the cell. The mitochondrion is a rod-shaped organelle with a single outer membrane and a highly folded inner membrane. These folds on the inner membrane are called cristae and the liquid inside the mitochondria is called the matrix. There are many mitochondria in a cell.

Cell types

As previously noted, there are many different types of cells in a plant (Table 1.2). They each have a different structure which conveys to them different functions.

Parenchyma

Parenchyma cells are usually relatively large, isodiametrically shaped cells with thin cell walls. They often function as storage cells.

Collenchyma

Collenchyma cells are thick-walled cells providing support to tissues, especially young, actively growing leaves and stems. The cell walls of collenchyma remain pliable, thus allowing for cellular expansion during growth. Both parenchyma and collenchyma cells can resume meristematic activity if needed, which is important for wound healing and cork formation.

Sclerenchyma

Sclerenchyma are also thick-walled cells that provide support, but their walls are not pliable and they often lack a protoplast at maturity, thus they cannot resume meristematic activity. At maturity they are considered non-living. Two distinct types of sclerenchyma are sclereids and fibers. Both sclereids and fibers offer support to plant tissues. Sclereids are often isodiametric in shape, but may also be somewhat elongated. Fibers tend to be many times longer than they are wide. While sclereids provide support in many different plant tissues, fibers are particularly important in support of vascular tissues.

Fibers are often associated with the bast fibers of commerce. Phloem fibers from dicots are often referred to as soft fibers since they remain soft and pliable at maturity. Fibers from monocots are often called hard fibers since they are stiff and non-pliable. Sometimes the fibers of commerce are not really even fibers at all. For example, cotton is composed of the epidermal hairs on seeds.

Table 1.2. Plant cell types and their function.

Cell type	Function(s)
Parenchyma	Storage of cellular metabolites Capable of meristematic activity
Collenchyma	Provide support Capable of meristematic activity
Sclerenchyma (sclereids and fibers)	Provide support
Tracheids	Lateral water and solute transport in xylem
Vessel elements	Lateral and longitudinal water and solute transport in xylem
Sieve elements	Transport of photosynthetic products
Companion cells	Provide energy to sieve elements for transport

Cells of the xylem

TRACHEIDS Tracheids are specialized cells of the xylem whose function is to transport water and solutes throughout the plant. They are characterized as elongated, thick-walled cells with pits. Pits are areas on the lateral external edges of some cell walls where secondary cell-wall thickening did not occur. Pits often occur in the same location of two adjacent cells and are called pit pairs. Pit pairs allow for the movement of substances transversely from cell to cell in the xylem. Functioning tracheids are non-living as the functioning protoplasm disintegrates upon cell maturity.

VESSEL ELEMENTS Tracheids that have perforations in the end walls of their cells are called vessel elements. Two or more vessel elements connected to each other are called vessels. Water movement in the xylem through tracheids occurs via the pit pairs. In vessels, water movement may be via pit pairs or longitudinally through the perforations in the end walls.

Cells of the phloem

SIEVE ELEMENTS Sieve elements are highly specialized cells in the phloem existing as sieve cells and sieve-tube members. Their function is to actively transport the products of photosynthesis to sites of utilization and storage within the plant. Both sieve cells and sieve-tube members are characterized as thick-walled, elongated cells with modified protoplasts. The protoplasts of laterally or vertically joined sieve elements are connected through pores in the cell walls. The areas on a cell wall where pores occur are called sieve areas. These pores are often much larger than the pores required for intercellular connections via plasmodesmata, and thus the two types of intercellular connections are different. Since functioning protoplasts are present at maturity, sieve elements are living, unlike the functioning cells of the xylem.

When the sieve areas of sieve elements are not very well developed or congregated at any specific area on the cell wall, the cells are called sieve cells rather than sieve elements. When the sieve areas are highly developed and tend to occur mostly on end walls, the cells are called sieve-tube members. A number of sieve-tube members vertically connected is called a sieve tube. Generally speaking, most gymnosperms have sieve cells while angiosperms have sieve tubes.

Protoplasts of both types of sieve elements change rather dramatically during maturation. Their nucleus, endoplasmic reticulum and ribosomes disappear. Additionally, the vacuole tonoplast disintegrates, leaving the plasmalemma to regulate cell turgidity. Starch accumulating plastids are retained (amyloplasts) and mitochondria are present. Thus the sieve cells or sieve-tube members have a plasmalemma with cytoplasm containing plastids and mitochondria.

COMPANION CELLS Specialized parenchyma cells associated laterally with sieve elements are called companion cells. Their function is to provide the cellular energy that is required for the movement of substances in the phloem. In gymnosperms, companion cells are called albuminous cells. Since movement of substances in the xylem does not require metabolic energy, there are no companion cells associated with functioning xylem cells.

Tissues

Tissues are highly organized groups of cells that perform a specific function. Each cell within the tissue has the basic cell attributes previously described yet each may have a specific function. All cells of the tissue are integrated in such a way that the tissue's function is achieved (Table 1.3).

Table 1.3. Plant tissues and their function(s) with general cellular composition of each tissue.

(a) Simple tissues (one cell type)

Plant tissue	Function(s)	Cell type(s)
Parenchyma	Storage Cell division	Parenchyma
Sclerenchyma	Support	Sclerenchyma
Collenchyma	Support	Collenchyma

(b) Complex tissue (more than one cell type)

Plant tissue	Function(s)	Cell type(s)
Epidermis	Protection from the elements Gas exchange Absorption of water and minerals Production of secretory metabolites	Parenchyma, guard cells, trichomes, root hairs
Vascular	Transport of water, nutrients, photosynthates, chemical messengers	Parenchyma, vessel elements, tracheids, sclereids, fibers, sieve elements, sieve-tube members, companion cells, fibers
Meristematic	Cell division	Initials, derivatives
Bark	Outer protective layer of woody plants	Phellogen, phelloderm, phellum, phelloid

Simple tissues – one cell type

Tissues in which there is only one cell type are called simple tissues. There are three simple tissues in plants: (i) parenchyma; (ii) sclerenchyma; and (iii) collenchyma. Notice how the tissue name indicates the cell type of the tissue.

PARENCHYMA The function of parenchyma is storage. The main substances stored in parenchyma are starch, fats, and proteins, depending on the organ the tissue is located in and the stage of plant development.

SCLERENCHYMA Sclerenchyma provides rigid strength to plant organs, especially in organs where further cell expansion is not likely to occur. Sclerenchyma is also quite evident in certain fruit. The pits of stone fruit such as peaches or cherries are composed primarily of sclerenchyma. In this case, sclerenchyma is providing protection to the developing seed inside the pit. Pear and quince (*Cydonia oblonga*) fruit have gritty textured sclerenchyma cells throughout the otherwise parenchymatic flesh. Pear, quince and apple cores also have significant sclerenchyma in them. Seed coats of many species have considerable sclerenchyma in them, providing protection to the enclosed embryo.

COLLENCHYMA Collenchyma provides flexible strength to plant organs, especially leaves and stems when expansion growth is likely to occur. The stalk (leaf petiole) of celery (*Apium graveolens*) has numerous areas of collenchyma tissue in it providing support and crunch.

Complex tissues – more than one cell type

Complex tissues generally have more than one cell type.

EPIDERMIS The epidermis is the outer protective layer on both roots (woody and herbaceous) and shoots (herbaceous) characterized by a layer of a fatty substance called cutin. Cutin helps reduce water loss through the epidermis and also helps prevent the intrusion of pathogens.

The epidermis is usually only one cell layer thick. Some plants have a multilayer epidermis, but this is relatively rare. An example is *Ficus elastica*. Epidermal cells are usually rectangular parenchyma cells, however, other cell types are also found in the epidermis. In general, epidermal cells do not photosynthesize to any great extent. An exception is that epidermal cells of many shade plants exhibit significant photosynthesis.

While the principle function of the epidermis is to create a barrier to the external environment, there are several other specialized functions of the epidermis due to the existence of highly specialized cells. These cells include root hairs, guard cells and trichomes.

Root hairs, as the name implies, occur in the epidermis of roots. They are irregularly shaped cells with a large surface area protruding into the soil matrix. Their function, due to the high surface area, is to increase absorption of water and solutes from the soil.

Guard cells form specialized pores called stomata in the epidermis. The function of stomata is gas exchange between the plant and the atmosphere. Thus, guard cells are most prevalent in the epidermis of leaves. They do occur on fruits and stems, but to a much lesser degree. Changes in the water content of guard cells determine whether or not the stomata are visible.

Many plants have specialized structures on the epidermis called trichomes. Trichomes can be single or multi-cellular. Root hairs are actually trichomes. Most trichomes secrete or store some secondary metabolite. Often, trichomes contain substances, which when released will deter feeding of insects. Thus at least one function of trichomes is in plant defense.

VASCULAR TISSUE Vascular tissue is responsible for long-range transport of substances in plants. Generally, xylem transports water and dissolved substances acropetally (from root to shoot tip) while phloem transports water and dissolved substances, primarily sugars, from the photosynthetic source (a leaf) to a sink (fruits, roots, developing tissue) in a basipetal direction. Movement in the xylem is passive and does not require metabolic energy while movement in the phloem is active and requires metabolic energy.

The main cell types in the xylem are vessel elements, tracheids, sclereids and fibers. Additionally, xylem contains parenchyma cells often protruding radially through the xylem. Their function is to store starch. The main cell types of the phloem include sieve elements, sieve-tube members, companion cells, fibers and sclereids.

MERISTEMATIC TISSUE Meristematic tissue is the tissue responsible for growth via cell division which occurs in many different parts of the plant. Meristematic cells are parenchyma cells which quickly differentiate into the many different cell types. Cells that retain the meristematic activity are called initials while those that begin differentiating are called derivatives. The vascular cambium is the tissue responsible for the production of xylem and phloem. Phellogen is tissue responsible for the production of cork and bark on woody stems. Apical meristems are responsible for growth at the apex of either roots or shoots. Increases in height or root depth are due to cell division in the apical meristem. (Of course cell division must be followed by cell elongation for significant root or shoot lengthening to occur.) Increases in root or stem circumference are due to the activity of vascular cambium and phellogen. The intercalary meristem or leaf cambium is responsible for cell division in leaf tissue. Buds are meristematic regions enclosed by protective bud scales. They are often categorized based on their ultimate fate (floral, vegetative or mixed) or their position (terminal, axillary or adventitious).

BARK Bark is the outermost protective tissue on woody plant stems. It is produced by the phellogen (cork cambium). Cells from the phellogen that are pushed inwards are called phelloderm. Other cells that are pushed outwards have a coating of suberin which is impermeable to water and gas. These cells soon die and become air filled and are called phellum cells (cork cells). Other cells produced by the phellogen and pushed outward that are not suberized are called phelloids. Since they lack suberin, they can exchange water, gas and nutrients, thus they are living.

Organs

Organs are major distinct and visibly differentiated groups of tissues characterized by a general purpose or function in the survival and/or reproduction of the plant. We generally consider six major organs of a plant: (i) roots; (ii) stems; (iii) leaves; (iv) flowers; (v) fruit; and (vi) seeds.

Roots

Roots are the main underground organ of the plant. Some roots are above ground, but most are beneath the soil surface. Roots anchor the plant in its growing medium. Roots are also responsible for the uptake and translocation of water and dissolved nutrients and may also serve as storage units for food reserves. Roots are also responsible for the production of growth regulating compounds, especially cytokinins.

Root growth is classified as either primary or secondary. Primary root growth is that root growth originating at the root apical meristem of the embryo in a seed. The root apical meristem is characterized by the presence of a protective root cap. This cap protects meristematic cells from the pressure generated by root elongation in the soil and also produces muscilage for lubricating the roots' penetration through the soil. The root cap is also responsible for geotropic responses via gravity-sensing plastids (amyloplasts). Primary root growth is also important in the production of growth regulators.

A cross-section of a primary root reveals three general regions: (i) the epidermis; (ii) the cortex; and (iii) the vascular region. The epidermis, as previously discussed, provides a barrier to the environment and also facilitates absorption from the soil via root hairs.

The cortex is a region of mostly parenchyma cells with the purpose of storage. The innermost layer of the cortex is called the endodermis. Cells of the endodermis have a covering of suberin called the casparian strip. This strip helps regulate water movement into the center of the root towards the vascular region. Just interior to the endodermis is the pericycle, the area of the cortex responsible for the origin of lateral roots.

The vascular region, located inside the pericycle is composed of xylem in the shape of a starfish, radiating out from the center of the root. The phloem is located between the arms of the xylem. The xylem and phloem together comprise the vascular cylinder which is called the stele.

Secondary root growth is growth which arises from vascular cambium and phellogen and results in an increase in root girth.

Adventitious root growth is root growth at sites on a plant not normally associated with root growth, such as at a node on a stem. Adventitious roots may remain primary or undergo secondary growth.

Roots have no leaves, nodes or internodes but may have buds. Roots with buds are often used in vegetative propagation.

Stems

Stems may be located above or below ground. Stems have leaves, buds, nodes and internodes and are thus easily distinguished from roots. Primary stem growth is from growth originating in the shoot apical meristem of an embryo and results in an increase in stem length. Secondary growth is via growth of vascular cambium and results in an increase in stem girth.

A cross-section of a stem reveals four main regions. The epidermis is the outer layer of the stem. Just in from the epidermis is the cortex. The cortex provides support and storage. The pith is a central core of parenchyma tissue in many stems. It is often crushed and destroyed by compression of secondary growth.

There are many different conformations of vascular tissues in plant stems. Vascular tissue is either scattered in the pith and cortex (monocots) or located between the pith and cortex (dicots).

Leaf arrangement on a stem is called phyllotaxy and it is very important in plant identification.

There are two very important distinctions between stem and root apices. One is that root apical meristems have a protective cap while stem apical meristems do not. The other is that stem apical meristems form lateral organs while root apices do not.

Leaves

True leaves are initiated via an apical meristem while seed leaves, or cotyledons, develop as part of the seed. True leaves consist of a lamina or leaf blade and a petiole. The lamina provides a large surface area for collecting light while the petiole holds the leaf erect and attaches it to the stem. A sessile leaf is a leaf without a petiole.

The thickened leaf base at the point of attachment to the stem is called the pulvinus. Stipules are small appendages often found at the base of the petiole. They are important in plant identification.

Leaves have three general tissue systems: (i) the epidermis; (ii) ground tissue; and (iii) vascular tissue.

The epidermis is the outermost layer with compactly arranged cells covered with a cuticle. There are stomata on one or both sides of the lamina.

Just interior to the epidermis is the ground tissue. The ground tissue is composed of spongy parenchyma and palisade parenchyma. The spongy parenchyma consists of loosely packed cells with significant intercellular spaces allowing for gas exchange. Spongy parenchyma cells are responsible for fixing carbon dioxide into carbohydrates during photosynthesis.

The palisade layer of parenchyma is one or more rows of tightly packed rectangular parenchyma cells oriented to intercept maximum light. They are just interior to the upper epidermis and are loaded with chloroplasts. Sometimes the two cell types are not distinguishable and are collectively referred to as mesophyll.

The leaf vascular system is the network of xylem and phloem throughout the spongy parenchyma or mesophyll.

The abscission zone, located at the base of the petiole (or the lamina in sessile leaves) is a region of cells which upon exposure to specific environmental signals, dissolve the glue between cells allowing for leaf abscission.

Flowers

Flowers are modified leaves. Upon exposure to specific environmental signals such as daylength or temperature or at a specific point of plant development, shoot apical meristems start to form flowers rather than leaves. The process is extremely important in horticulture and will be covered in depth later (see Chapter 5, this volume).

Flowers are the reproductive shoot of an angiosperm (seed-bearing plant). They are composed of four whorls of modified leaves. Two sterile whorls include the sepals and the petals while two fertile whorls include the carpels and the stamen. The four whorls are attached to a common base or receptacle.

The outermost whorl is the calyx which is composed of individual sepals. The whorl just interior to the sepals is the corolla which is composed of petals. The calyx and corolla together comprise the perianth. The purpose of the perianth is to protect the fertile whorls and in some cases, to attract pollinators. If the petals and sepals cannot be distinguished, they are called tepals.

The two inner whorls include the stamen (collectively the androecium) which produce pollen grains followed by the carpels (collectively the gynoecium) which produce the eggs. Sexual reproduction results from pollination followed by fertilization and the subsequent production of seeds.

Besides being important in propagation, seeds are also usually required for proper fruit development. Seedless fruit are parthenocarpic. Parthenocarpic fruit develop from a flower in which the embryo has aborted.

The gynoecium is the megasporophyll and is composed of one or more carpels (modified leaves). The pistil in a flower is composed of one or more carpels and has three major parts: (i) the stigma; (ii) the style; and (iii) the ovary.

The androecium is the microsporophyll and includes the stamen. There are usually many stamens in a flower. Each stamen is composed of a filament holding an anther aloft. The anther is divided into pollen sacs which produce pollen grains. Each pollen grain in angiosperms consists of three cells surrounded by a thick protective wall. One cell is responsible for pollen tube growth down the style of the pistil, while the other two are generative nuclei. One sperm cell will unite with an egg cell to form the zygote while the other sperm cell fuses with the polar nuclei of the ovary to form the endosperm. This process is called double fertilization.

Fruit

Fruit is botanically defined as a ripened, mature ovary. A more acceptable definition considers that fruit may be derived from extracarpellary tissues as well as ovarian tissues which are united at maturity to form the harvested commodity. The simplest type of fruit is a single ripened carpel from a single ovary. An example is the peach. The pericarp is the ovary wall and it is divided into: (i) the exocarp (skin of the peach); (ii) the mesocarp (the flesh); and (iii) the endocarp (the pit). Inside the pericarp is one or more ripened ovules, or seeds.

Seeds

Most seeds are the result of double fertilization. The hard, outer coat is called the testa. Within the seed lies the embryo, a small diploid plant formed by fertilization of an egg by a pollen generative nucleus. The embryo has several major components including: (i) the cotyledons; (ii) the epicotyls; and (iii) the hypocotyl.

Cotyledons are also called seed leaves. They store energy needed for germination and become the first photosynthesizing organ of a seedling. Angiosperms have either one (monocots) or two (dicots) cotyledons. Gymnosperms may have many cotyledons. The epicotyl is the portion of the embryo above the cotyledons. The plumule is the meristematic apical tip of the embryo located at the apex of the epicotyl. The hypocotyl is the portion of the embryo below the cotyledons which terminates as the radicle, or embryonic root.

Plant Types

Humans love to classify things including plants. We classify them according to: (i) scientific nomenclature; (ii) growth cycle; (iii) stem growth; (iv) discipline; and (v) use.

Based on taxonomy – scientific classification

The most useful and widely accepted form of plant classification is that based on taxonomy. Plants are grouped together using morphological, anatomical, chemical and growth similarities. This type of classification is dynamic as classifications are revised as needed, based on new knowledge. There are seven main levels of taxonomic classification including: (i) kingdom; (ii) division; (iii) class; (iv) order; (v) family; (vi) genus; and (vii) species. Kingdom is the most inclusive while species is the least inclusive. Species is further divided into group or botanical variety and horticultural variety (or cultivar). A very good reference on the subject is Stuessy's (2008) text.

The practical use of taxonomic nomenclature ensures that we are talking about the same plant wherever we are on earth. We generally limit our plant name to one including genus, species, perhaps group, and finally cultivar. This text focuses on organisms in only one of the five kingdoms, and that is the plant kingdom or *Plantae*. All organisms in this kingdom have photosynthesis in common. Additionally, they are all eukaryotic, having differentiated cell types which contain vacuoles, chloroplasts and are surrounded by cell walls. They also reproduce either asexually or sexually via the alternation of generations. Within the plant kingdom there are vascular or non-vascular plants. Vascular plants reproduce via either seeds or spores.

This text also focuses on two seeded divisions within the vascular plants: (i) the *Pinophyta* (gymnosperms) where seeds are born on a cone; and (ii) the *Magnoliophyta* (angiosperms) where seeds reside in an ovary. Within the *Magnoliophyta*, we study two classes, the *Liliopsida* or monocots and the *Magnoliopsida* or dicots. Characteristics common to monocots include parallel leaf veins, flower parts in multiples of three, fibrous root systems, vascular bundles scattered in the pith and no annual growth rings. A monocot embryo has one cotyledon or seed leaf, hence the name. Characteristics common to dicots include a network of leaf veins, flower parts in multiples of four or five, tap roots with branches, and a vascular bundle in a single cylinder which results in the formation of growth rings. A dicot embryo has two cotyledons.

Within class we continue classifying into order, family, genus and species. Linnaeus developed the binomial system of plant nomenclature (Genus species) which is still used today. This system relies heavily on floral morphology.

Within Genus species we may identify the group (which used to be the botanical variety) and the cultivar which stands for cultivated variety. Horticulturists should make sure they consistently use the term cultivar rather than variety, since in almost all cases they are referring to the cultivar name and not the botanical variety.

The International Code of Nomenclature for Cultivated Plants

There are specific rules for writing the Latin binomial (McNeill *et al.*, 2006). The first letter of the genus is always capitalized and the species is always lower case. Both genus and species are italicized or underlined, but not both, and the space between the genus and the species should not be underlined. The scientist responsible for naming the plant may be indicated with an initial (e.g. L., which stands for Linnaeus). Any revision to the original nomenclature is acknowledged after the original authority. The genus can stand alone but the species is never presented without the genus. The group may or may not be included, followed by the cultivar.

A good example of where the group is important in horticulture is in the family *Brassicaceae*. All of your childhood favorites are included in *Brassica oleracea*. To further categorize these vegetables correctly, we must include the botanical variety. When we need to use the botanical variety, it is because we have a group of related cultivars. We therefore indicate a group such as the Acephala Group, which includes the cultivars of kale. Note that neither the word 'group' nor the group name is italicized, and both are always capitalized. Thus we would present kale as *Brassica oleracea* Acephala Group. Note the cultivar has not been indicated.

When we want to identify a specific cultivar, we include it in the name according to the following example. Suppose we wanted to present the cabbage cultivar 'Copenhagen Market' in a report we were writing. We would indicate: *Brassica oleracea* (Capitata Group) 'Copenhagen Market'. Note the cultivar name is not italicized, but rather, is enclosed in single quotes, and the group designation is enclosed in parentheses. Presentation of the cultivar using the cv. abbreviation and omitting the single quotes, such as: *Brassica oleracea* (Capitata Group) cv. Copenhagen Market is no longer acceptable.

To be complete, here's a list of your favorites (Fig. 1.2):

- *Brassica oleracea* Acephala Group – kale;
- *Brassica oleracea* Gemmifera Group – Brussels sprouts;
- *Brassica oleracea* Italica Group – broccoli;
- *Brassica oleracea* Botrytis Group – cauliflower;
- *Brassica oleracea* Caulorapa Group – kohlrabi; and
- *Brassica oleracea* Capitata Group – cabbage.

Classification by growth cycle

Plants are also often classified based on their growth cycle. In defining a particular growth cycle, we examine how long it takes for the plant to produce seeds from a seed. The time it takes is measured in growing seasons. We may also add descriptive terms to the definition to further categorize the plants in question.

Annual

Annuals are plants that produce seeds in one growing season and then die. Summer annuals complete their life cycle during the summer growing season (spring to fall) while winter annuals complete their life cycle over the winter growing season (fall to spring).

Biennial

Biennials require two growing seasons (usually summer) to produce seed. The two growing seasons are separated by a period of little to no growth while the plants are subjected to cold temperatures. This exposure to cold to induce or facilitate flowering and subsequent seed production is called vernalization. Biennial plants die after the second growing season.

Perennial

Perennial plants have the potential to produce seed every growing season after reaching a certain age (different for each species) and the plants may be very long lived. Perennial plants which go through a cyclical pattern of active growth followed by greatly reduced visible growth and shedding of

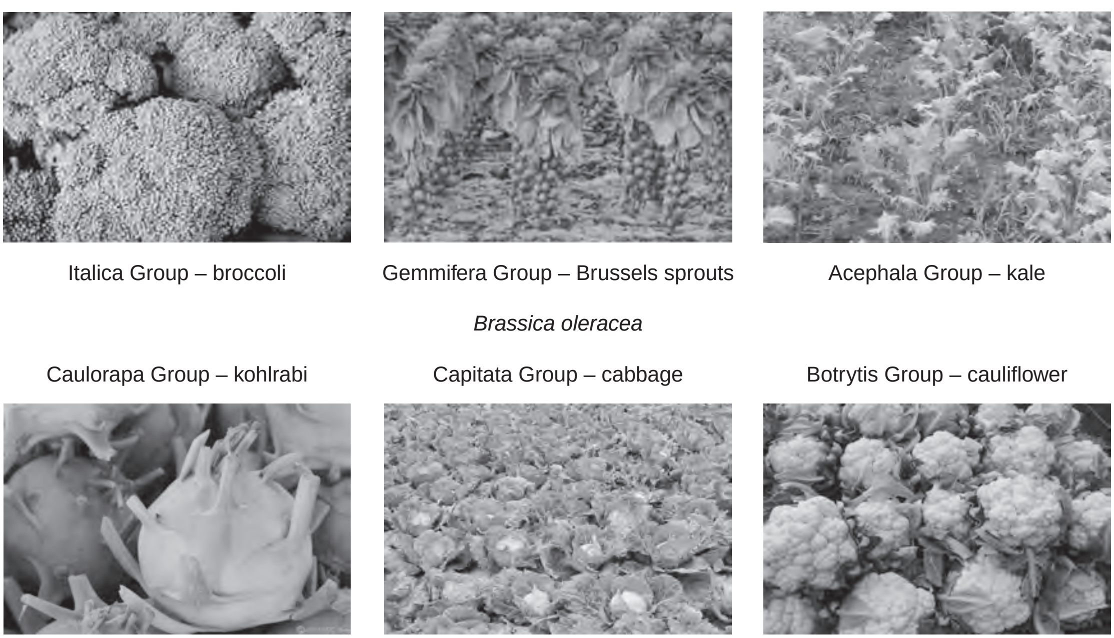

Fig. 1.2. Six major brassica commodities, all *Brassica oleracea.* Commodities are distinguished within species by different botanical groups.

leaves are called deciduous. Perennial plants which retain their leaves year-round, only shedding some of them over time, are called evergreen.

Classification by stem growth

We also classify plants according to the nature of their stem growth. Even though we like to list specific categories, there are many variations of the following plant types.

Herbs

Plants that produce soft, non-woody stems are called herbaceous. Herbaceous plants are often annuals. They are also usually relatively small in stature.

Shrubs

Plants with stems which become woody and have a number of co-dominant main stems arising at ground level, rather than one main trunk are called shrubs.

Trees

Trees are plants where the stem becomes woody and there is one main dominant trunk. Branching often occurs on the upper end of the main trunk

Classification by discipline

Plants can also be classified based upon which discipline of agriculture studies them. Generally we consider agronomic versus horticultural crops. Most crops are studied by either agronomists or horticulturists. A further characteristic which helps to place a crop under one or the other designation is the intensity of production. Horticultural crops often require intensive production practices while agronomic crops are usually less intensively grown. Sometimes the distinction is not really clear. For example, sweet corn (*Zea mays*) is a horticultural crop while field corn (*Zea mays*) is an agronomic crop. Thus their use helps to further classify them. Sweet corn is usually food (food for humans) while field corn is usually feed (food for animals) or grown for industrial use (starch, oil).

Classification by use

A plants ultimate use may determine its classification.

Ornamental

Plants used in the landscape or for other primarily aesthetic reasons are called ornamentals. Ornamentals are usually divided into landscape plants and floricultural crops.

Industrial

Many plants are grown for industrial uses, both agricultural and non-agricultural. They are all generally considered to be agronomic crops. Some non-agricultural uses might include drugs, latex, fiber, lumber or oil. Crops grown for use in agriculture, but not for direct human consumption are included in this category. Such crops would include hay, forage, silage, sugar, grains, cereal, pulses (grain legumes), green manure, cover crop, trap crop, and companion plantings.

Vegetable versus fruit

In horticulture, we often distinguish between fruits and vegetables. The botanical distinction is clear. However, the horticultural distinction of a fruit or vegetable may not be quite as clear. Any vegetative plant part that is consumed is always considered a vegetable. The distinction may be less clear when dealing with botanical fruit. If the botanical fruit (or fruit precursor, i.e. flower bud or flower) or product made from it is usually consumed as a major part of a meal, and is often savory rather than sweet, it is considered a vegetable. If it is consumed after the main meal or as a snack, and is usually sweet rather than savory, it is considered a fruit.