they may find favorable and less competitive conditions in which to germinate and grow.

Some fruit have built-in mechanisms so they can disperse by themselves, whereas others require the help of agents like wind, water, and animals (Figure 32.23). Modifications in seed structure, composition, and size help in dispersal. Wind-dispersed fruit are lightweight and may have wing-like appendages that allow them to be carried by the wind. Some have a parachute-like structure to keep them afloat. Some fruits—for example, the dandelion—have hairy, weightless structures that are suited to dispersal by wind.

Seeds dispersed by water are contained in light and buoyant fruit, giving them the ability to float. Coconuts are well known for their ability to float on water to reach land where they can germinate. Similarly, willow and silver birches produce lightweight fruit that can float on water.

Animals and birds eat fruits, and the seeds that are not digested are excreted in their droppings some distance away. Some animals, like squirrels, bury seed-containing fruits for later use; if the squirrel does not find its stash of fruit, and if conditions are favorable, the seeds germinate. Some fruits, like the cocklebur, have hooks or sticky structures that stick to an animal's coat and are then transported to another place. Humans also play a big role in dispersing seeds when they carry fruits to new places and throw away the inedible part that contains the seeds.

All of the above mechanisms allow for seeds to be dispersed through space, much like an animal's offspring can move to a new location. Seed dormancy, which was described earlier, allows plants to disperse their progeny through time: something animals cannot do. Dormant seeds can wait months, years, or even decades for the proper conditions for germination and propagation of the species.

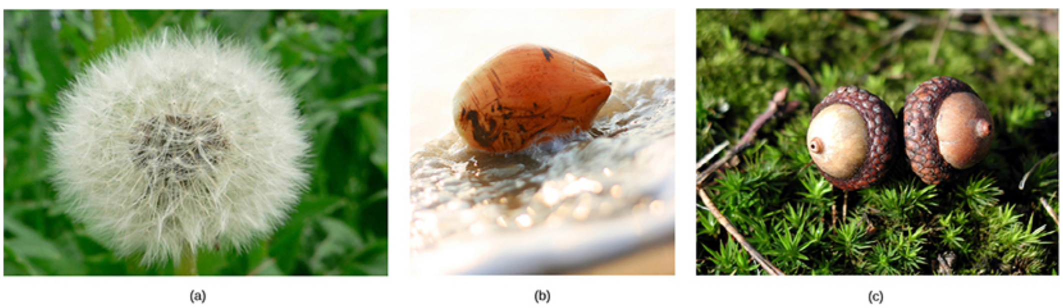

Figure 32.23 Fruits and seeds are dispersed by various means. (a) Dandelion seeds are dispersed by wind, the (b) coconut seed is dispersed by water, and the (c) acorn is dispersed by animals that cache and then forget it. (credit a: modification of work by "Rosendahl"/Flickr; credit b: modification of work by Shine Oa; credit c: modification of work by Paolo Neo)

32.3 Asexual Reproduction

By the end of this section, you will be able to do the following:

- Compare the mechanisms and methods of natural and artificial asexual reproduction
- Describe the advantages and disadvantages of natural and artificial asexual reproduction
- Discuss plant life spans

Many plants are able to propagate themselves using asexual reproduction. This method does not require the investment required to produce a flower, attract pollinators, or find a means of seed dispersal. Asexual reproduction produces plants that are genetically identical to the parent plant because no mixing of male and female gametes takes place. Traditionally, these plants survive well under stable environmental conditions when compared with plants produced from sexual reproduction because they carry genes identical to those of their parents.

Many different types of roots exhibit asexual reproduction (Figure 32.24). The corm is used by gladiolus and garlic. Bulbs, such as a scaly bulb in lilies and a tunicate bulb in daffodils, are other common examples. A potato is a stem tuber, while parsnip propagates from a taproot. Ginger and iris produce rhizomes, while ivy uses an adventitious root (a root arising from a plant part other than the main or primary root), and the strawberry plant has a stolon, which is also called a runner.

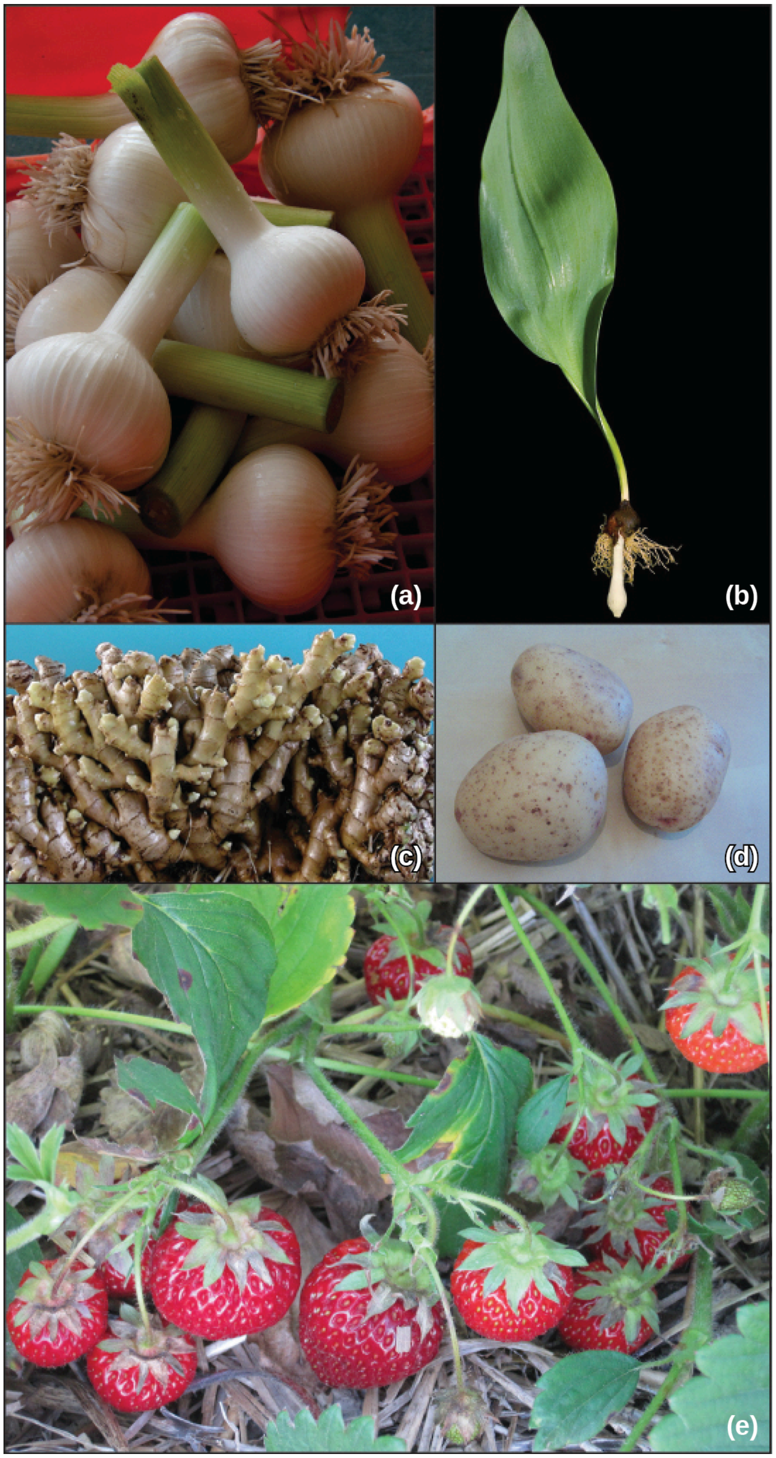

Figure 32.24 Different types of stems allow for asexual reproduction. (a) The corm of a garlic plant looks similar to (b) a tulip bulb, but the corm is solid tissue, while the bulb consists of layers of modified leaves that surround an underground stem. Both corms and bulbs can self-propagate, giving rise to new plants. (c) Ginger forms masses of stems called rhizomes that can give rise to multiple plants. (d) Potato plants form fleshy stem tubers. Each eye in the stem tuber can give rise to a new plant. (e) Strawberry plants form stolons: stems that grow at the soil surface or just below ground and can give rise to new plants. (credit a: modification of work by Dwight Sipler; credit c: modification of work by Albert Cahalan, USDA ARS; credit d: modification of work by Richard North; credit e: modification of work by Julie Magro)

Some plants can produce seeds without fertilization. Either the ovule or part of the ovary, which is diploid in nature, gives rise to a new seed. This method of reproduction is known as **apomixis**.

An advantage of asexual reproduction is that the resulting plant will reach maturity faster. Since the new plant is arising from an adult plant or plant parts, it will also be sturdier than a seedling. Asexual reproduction can take place by natural or artificial (assisted by humans) means.

Natural Methods of Asexual Reproduction

Natural methods of asexual reproduction include strategies that plants have developed to self-propagate. Many plants—like ginger, onion, gladioli, and dahlia—continue to grow from buds that are present on the surface of the stem. In some plants, such as the sweet potato, adventitious roots or runners can give rise to new plants (Figure 32.25). In *Bryophyllum* and kalanchoe, the leaves have small buds on their margins. When these are detached from the plant, they grow into independent plants; or, they may start growing into independent plants if the leaf touches the soil. Some plants can be propagated through cuttings alone.

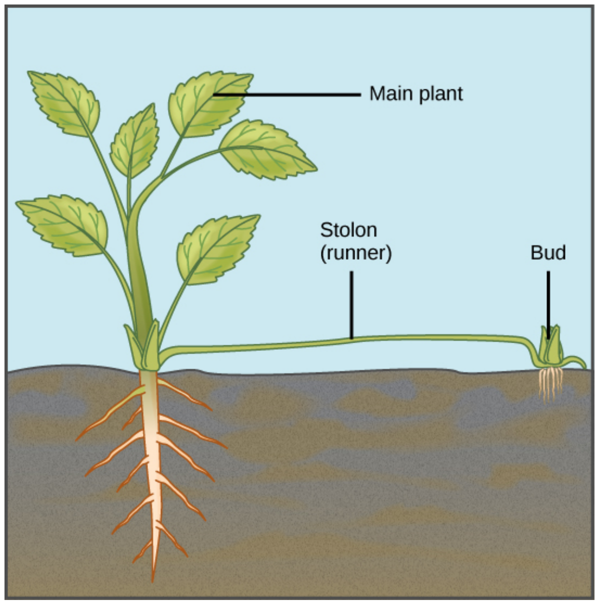

Figure 32.25 A stolon, or runner, is a stem that runs along the ground. At the nodes, it forms adventitious roots and buds that grow into a new plant.

Artificial Methods of Asexual Reproduction

These methods are frequently employed to give rise to new, and sometimes novel, plants. They include grafting, cutting, layering, and micropropagation.

Grafting

Grafting has long been used to produce novel varieties of roses, citrus species, and other plants. In **grafting**, two plant species are used; part of the stem of the desirable plant is grafted onto a rooted plant called the stock. The part that is grafted or attached is called the **scion**. Both are cut at an oblique angle (any angle other than a right angle), placed in close contact with each other, and are then held together (Figure 32.26). Matching up these two surfaces as closely as possible is extremely important because these will be holding the plant together. The vascular systems of the two plants grow and fuse, forming a graft. After a period of time, the scion starts producing shoots, and eventually starts bearing flowers and fruits. Grafting is widely used in viticulture (grape growing) and the citrus industry. Scions capable of producing a particular fruit variety are grafted onto root stock with specific resistance to disease.

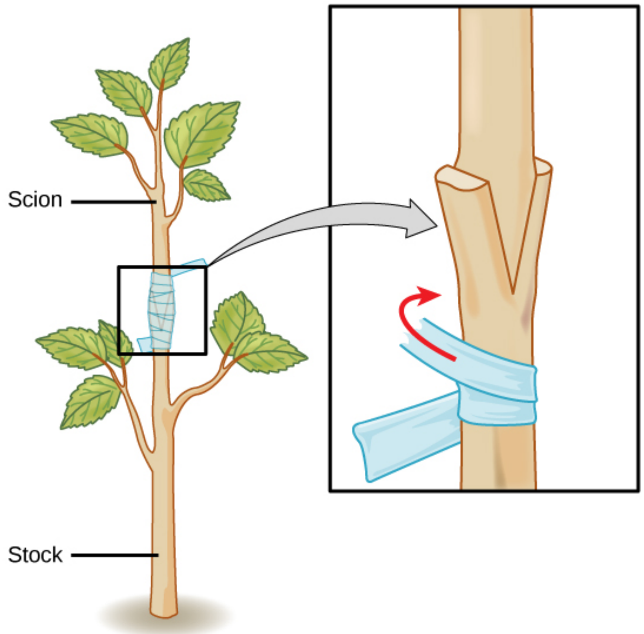

Figure 32.26 Grafting is an artificial method of asexual reproduction used to produce plants combining favorable stem characteristics with favorable root characteristics. The stem of the plant to be grafted is known as the scion, and the root is called the stock.

Cutting

Plants such as coleus and money plant are propagated through stem **cuttings**, where a portion of the stem containing nodes and internodes is placed in moist soil and allowed to root. In some species, stems can start producing a root even when placed only in water. For example, leaves of the African violet will root if kept in water undisturbed for several weeks.

Layering

Layering is a method in which a stem attached to the plant is bent and covered with soil. Young stems that can be bent easily without any injury are preferred. Jasmine and bougainvillea (paper flower) can be propagated this way (Figure 32.27). In some plants, a modified form of layering known as air layering is employed. A portion of the bark or outermost covering of the stem is removed and covered with moss, which is then taped. Some gardeners also apply rooting hormone. After some time, roots will appear, and this portion of the plant can be removed and transplanted into a separate pot.

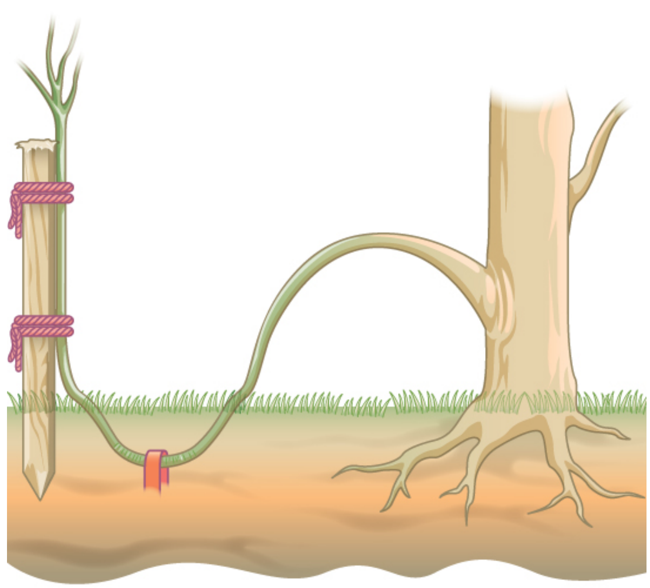

Figure 32.27 In layering, a part of the stem is buried so that it forms a new plant. (credit: modification of work by Pearson Scott Foresman, donated to the Wikimedia Foundation)

Micropropagation

Micropropagation (also called plant tissue culture) is a method of propagating a large number of plants from a single plant in a short time under laboratory conditions (Figure 32.28). This method allows propagation of rare, endangered species that may be difficult to grow under natural conditions, are economically important, or are in demand as disease-free plants.

Figure 32.28 Micropropagation is used to propagate plants in sterile conditions. (credit: Nikhilesh Sanyal)

To start plant tissue culture, a part of the plant such as a stem, leaf, embryo, anther, or seed can be used. The plant material is thoroughly sterilized using a combination of chemical treatments standardized for that species. Under sterile conditions, the plant material is placed on a plant tissue culture medium that contains all the minerals, vitamins, and hormones required by the plant. The plant part often gives rise to an undifferentiated mass known as callus, from which individual plantlets begin to grow after a period of time. These can be separated and are first grown under greenhouse conditions before they are moved to field conditions.

Plant Life Spans

The length of time from the beginning of development to the death of a plant is called its life span. The life cycle, on the other hand, is the sequence of stages a plant goes through from seed germination to seed production of the mature plant. Some plants, such as annuals, only need a few weeks to grow, produce seeds and die. Other plants, such as the bristlecone pine, live for thousands of years. Some bristlecone pines have a documented age of 4,500 years (Figure 32.29). Even as some parts of a plant, such as regions containing meristematic tissue—the area of active plant growth consisting of undifferentiated cells capable of cell division—continue to grow, some parts undergo programmed cell death (apoptosis). The cork found on stems, and the water-conducting tissue of the xylem, for example, are composed of dead cells.

Figure 32.29 The bristlecone pine, shown here in the Ancient Bristlecone Pine Forest in the White Mountains of eastern California, has been known to live for 4,500 years. (credit: Rick Goldwaser)

Plant species that complete their lifecycle in one season are known as annuals, an example of which is *Arabidopsis*, or mouse-ear cress. Biennials such as carrots complete their lifecycle in two seasons. In a biennial's first season, the plant has a vegetative phase, whereas in the next season, it completes its reproductive phase. Commercial growers harvest the carrot roots after the first year of growth, and do not allow the plants to flower. Perennials, such as the magnolia, complete their lifecycle in two years or more.

In another classification based on flowering frequency, **monocarpic** plants flower only once in their lifetime; examples include bamboo and yucca. During the vegetative period of their life cycle (which may be as long as 120 years in some bamboo species), these plants may reproduce asexually and accumulate a great deal of food material that will be required during their once-in-a-lifetime flowering and setting of seed after fertilization. Soon after flowering, these plants die. **Polycarpic** plants form flowers many times during their lifetime. Fruit trees, such as apple and orange trees, are polycarpic; they flower every year. Other polycarpic species, such as perennials, flower several times during their life span, but not each year. By this means, the plant does not require all its nutrients to be channelled towards flowering each year.

As is the case with all living organisms, genetics and environmental conditions have a role to play in determining how long a plant will live. Susceptibility to disease, changing environmental conditions, drought, cold, and competition for nutrients are some of the factors that determine the survival of a plant. Plants continue to grow, despite the presence of dead tissue such as cork. Individual parts of plants, such as flowers and leaves, have different rates of survival. In many trees, the older leaves turn yellow and eventually fall from the tree. Leaf fall is triggered by factors such as a decrease in photosynthetic efficiency, due to shading by upper leaves, or oxidative damage incurred as a result of photosynthetic reactions. The components of the part to be shed are recycled by the plant for use in other processes, such as development of seed and storage. This process is known as nutrient recycling.

The aging of a plant and all the associated processes is known as **senescence**, which is marked by several complex biochemical changes. One of the characteristics of senescence is the breakdown of chloroplasts, which is characterized by the yellowing of leaves. The chloroplasts contain components of photosynthetic machinery such as membranes and proteins. Chloroplasts also contain DNA. The proteins, lipids, and nucleic acids are broken down by specific enzymes into smaller molecules and salvaged by the plant to support the growth of other plant tissues.

The complex pathways of nutrient recycling within a plant are not well understood. Hormones are known to play a role in senescence. Applications of cytokinins and ethylene delay or prevent senescence; in contrast, abscissic acid causes premature onset of senescence.

KEY TERMS

accessory fruit fruit derived from tissues other than the ovary
aggregate fruit fruit that develops from multiple carpels in the same flower
aleurone single layer of cells just inside the seed coat that secretes enzymes upon germination
androecium sum of all the stamens in a flower
antipodals the three cells away from the micropyle
apomixis process by which seeds are produced without fertilization of sperm and egg
coleoptile covering of the shoot tip, found in germinating monocot seeds
coleorhiza covering of the root tip, found in germinating monocot seeds
cotyledon fleshy part of seed that provides nutrition to the seed
cross-pollination transfer of pollen from the anther of one flower to the stigma of a different flower
cutting method of asexual reproduction where a portion of the stem contains nodes and internodes is placed in moist soil and allowed to root
dormancy period of no growth and very slow metabolic processes
double fertilization two fertilization events in angiosperms; one sperm fuses with the egg, forming the zygote, whereas the other sperm fuses with the polar nuclei, forming endosperm
endocarp innermost part of fruit
endosperm triploid structure resulting from fusion of a sperm with polar nuclei, which serves as a nutritive tissue for embryo
endospermic dicot dicot that stores food reserves in the endosperm
epicotyl embryonic shoot above the cotyledons
exine outermost covering of pollen
exocarp outermost covering of a fruit
gametophyte multicellular stage of the plant that gives rise to haploid gametes or spores
grafting method of asexual reproduction where the stem from one plant species is spliced to a different plant
gravitropism response of a plant growth in the same direction as gravity
gynoecium the sum of all the carpels in a flower
hypocotyl embryonic axis above the cotyledons
intine inner lining of the pollen
layering method of propagating plants by bending a stem under the soil
megagametogenesis second phase of female gametophyte development, during which the surviving haploid megaspore undergoes mitosis to produce an eight-nucleate, seven-cell female gametophyte, also known as the megagametophyte or embryo sac.
megasporangium tissue found in the ovary that gives rise to the female gamete or egg
megasporogenesis first phase of female gametophyte development, during which a single cell in the diploid megasporangium undergoes meiosis to produce four megaspores, only one of which survives
megasporophyll bract (a type of modified leaf) on the central axis of a female gametophyte
mesocarp middle part of a fruit
micropropagation propagation of desirable plants from a plant part; carried out in a laboratory
micropyle opening on the ovule sac through which the pollen tube can gain entry
microsporangium tissue that gives rise to the microspores or the pollen grain
microsporophyll central axis of a male cone on which bracts (a type of modified leaf) are attached
monocarpic plants that flower once in their lifetime
multiple fruit fruit that develops from multiple flowers on an inflorescence
nectar guide pigment pattern on a flower that guides an insect to the nectaries
non-endospermic dicot dicot that stores food reserves in the developing cotyledon
perianth (also, petal or sepal) part of the flower consisting of the calyx and/or corolla; forms the outer envelope of the flower
pericarp collective term describing the exocarp, mesocarp, and endocarp; the structure that encloses the seed and is a part of the fruit
plumule shoot that develops from the germinating seed
polar nuclei found in the ovule sac; fusion with one sperm cell forms the endosperm
pollination transfer of pollen to the stigma
polycarpic plants that flower several times in their lifetime
radicle original root that develops from the germinating seed
scarification mechanical or chemical processes to soften the seed coat
scion the part of a plant that is grafted onto the root stock of another plant
scutellum type of cotyledon found in monocots, as in grass seeds
self-pollination transfer of pollen from the anther to the stigma of the same flower
senescence process that describes aging in plant tissues
simple fruit fruit that develops from a single carpel or fused carpels
sporophyte multicellular diploid stage in plants that is formed after the fusion of male and female gametes
suspensor part of the growing embryo that makes connection with the maternal tissues

synergid type of cell found in the ovule sac that secretes chemicals to guide the pollen tube towards the egg
tegmen inner layer of the seed coat
testa outer layer of the seed coat
vernalization exposure to cold required by some seeds before they can germinate

CHAPTER SUMMARY

32.1 Reproductive Development and Structure

The flower contains the reproductive structures of a plant. All complete flowers contain four whorls: the calyx, corolla, androecium, and gynoecium. The stamens are made up of anthers, in which pollen grains are produced, and a supportive strand called the filament. The pollen contains two cells— a generative cell and a tube cell—and is covered by two layers called the intine and the exine. The carpels, which are the female reproductive structures, consist of the stigma, style, and ovary. The female gametophyte is formed from mitotic divisions of the megaspore, forming an eight-nuclei ovule sac. This is covered by a layer known as the integument. The integument contains an opening called the micropyle, through which the pollen tube enters the embryo sac.

The diploid sporophyte of angiosperms and gymnosperms is the conspicuous and long-lived stage of the life cycle. The sporophytes differentiate specialized reproductive structures called sporangia, which are dedicated to the production of spores. The microsporangium contains microspore mother cells, which divide by meiosis to produce haploid microspores. The microspores develop into male gametophytes that are released as pollen. The megasporangium contains megaspore mother cells, which divide by meiosis to produce haploid megaspores. A megaspore develops into a female gametophyte containing a haploid egg. A new diploid sporophyte is formed when a male gamete from a pollen grain enters the ovule sac and fertilizes this egg.

32.2 Pollination and Fertilization

For fertilization to occur in angiosperms, pollen has to be transferred to the stigma of a flower: a process known as pollination. Gymnosperm pollination involves the transfer of pollen from a male cone to a female cone. When the pollen of the flower is transferred to the stigma of the same or another flower on the same plant, it is called self-pollination. Cross-pollination occurs when pollen is transferred from one flower to another flower of another plant. Cross-pollination requires pollinating agents such as water, wind, or animals, and increases genetic diversity. After the pollen lands on the stigma, the tube cell gives rise to the pollen tube, through which the generative nucleus migrates. The pollen tube gains entry through the micropyle on the ovule sac. The generative cell divides to form two sperm cells: one fuses with the egg to form the diploid zygote, and the other fuses with the polar nuclei to form the endosperm, which is triploid in nature. This is known as double fertilization. After fertilization, the zygote divides to form the embryo and the fertilized ovule forms the seed. The walls of the ovary form the fruit in which the seeds develop. The seed, when mature, will germinate under favorable conditions and give rise to the diploid sporophyte.

32.3 Asexual Reproduction

Many plants reproduce asexually as well as sexually. In asexual reproduction, part of the parent plant is used to generate a new plant. Grafting, layering, and micropropagation are some methods used for artificial asexual reproduction. The new plant is genetically identical to the parent plant from which the stock has been taken. Asexually reproducing plants thrive well in stable environments.

Plants have different life spans, dependent on species, genotype, and environmental conditions. Parts of the plant, such as regions containing meristematic tissue, continue to grow, while other parts experience programmed cell death. Leaves that are no longer photosynthetically active are shed from the plant as part of senescence, and the nutrients from these leaves are recycled by the plant. Other factors, including the presence of hormones, are known to play a role in delaying senescence.

VISUAL CONNECTION QUESTIONS

1. Figure 32.3 If the anther is missing, what type of reproductive structure will the flower be unable to produce? What term is used to describe an incomplete flower lacking the androecium? What term describes an incomplete flower lacking a gynoecium?

2. Figure 32.8 An embryo sac is missing the synergids. What specific impact would you expect this to have on fertilization?
   a. The pollen tube will be unable to form.
   b. The pollen tube will form but will not be guided toward the egg.
   c. Fertilization will not occur because the synergid is the egg.
   d. Fertilization will occur but the embryo will not be able to grow.

3. Figure 32.20 What is the function of the cotyledon?
   a. It develops into the root.
   b. It provides nutrition for the embryo.
   c. It forms the embryo.
   d. It protects the embryo.

REVIEW QUESTIONS

4. In a plant's male reproductive organs, development of pollen takes place in a structure known as the ________.
   a. stamen
   b. microsporangium
   c. anther
   d. tapetum

5. The stamen consists of a long stalk called the filament that supports the ________.
   a. stigma
   b. sepal
   c. style
   d. anther

6. The ________ are collectively called the calyx.
   a. sepals
   b. petals
   c. tepals
   d. stamens

7. The pollen lands on which part of the flower?
   a. stigma
   b. style
   c. ovule
   d. integument

8. After double fertilization, a zygote and ________ form.
   a. an ovule
   b. endosperm
   c. a cotyledon
   d. a suspensor

9. The fertilized ovule gives rise to the ________.
   a. fruit
   b. seed
   c. endosperm
   d. embryo

10. What is the term for a fruit that develops from tissues other than the ovary?
    a. simple fruit
    b. aggregate fruit
    c. multiple fruit
    d. accessory fruit

11. The ________ is the outermost covering of a fruit.
    a. endocarp
    b. pericarp
    c. exocarp
    d. mesocarp

12. ________ is a useful method of asexual reproduction for propagating hard-to-root plants.
    a. grafting
    b. layering
    c. cuttings
    d. budding

13. Which of the following is an advantage of asexual reproduction?
    a. Cuttings taken from an adult plant show increased resistance to diseases.
    b. Grafted plants can more successfully endure drought.
    c. When cuttings or buds are taken from an adult plant or plant parts, the resulting plant will grow into an adult faster than a seedling.
    d. Asexual reproduction takes advantage of a more diverse gene pool.

14. Plants that flower once in their lifetime are known as ________.
    a. monoecious
    b. dioecious
    c. polycarpic
    d. monocarpic

15. Plant species that complete their lifecycle in one season are known as ________.
    a. biennials
    b. perennials
    c. annuals
    d. polycarpic

CRITICAL THINKING QUESTIONS

16. Describe the reproductive organs inside a flower.
17. Describe the two-stage lifecycle of plants: the gametophyte stage and the sporophyte stage.
18. Describe the four main parts, or whorls, of a flower.
19. Discuss the differences between a complete flower and an incomplete flower.
20. Why do some seeds undergo a period of dormancy, and how do they break dormancy?
21. Discuss some ways in which fruit seeds are dispersed.
22. What are some advantages of asexual reproduction in plants?
23. Describe natural and artificial methods of asexual reproduction in plants.
24. Discuss the life cycles of various plants.
25. How are plants classified on the basis of flowering frequency?