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Biology and Classification of Vegetables

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Introduction

Vegetables enrich and diversify the human diet, and are essential to human health (Dias 2012; Keatinge et al. 2011). They are the primary source of mineral nutrients, vitamins, secondary plant metabolites, and other compounds that support human health and nutrition. Vegetables, especially roots and tubers, can also possess significant caloric value, serving as staple crops in many parts of the world, particularly in the tropics. Although vegetables account for less than 1% of the world's plants, the genetic, anatomical, and morphological diversity of vegetables as a group is astounding (Pitrat and Audergon 2015). Hundreds of vegetable taxa are grown for food in subsistence and commercial agricultural systems worldwide (Welbaum 2015).

Biology and Classification of Vegetables

Vegetables as a group are diverse and a primary reason for this diversity is the broad definition of the word *vegetable* itself. Any plant part consumed for food that is not a mature fruit or seed is by definition a vegetable. These include petioles (e.g., celery, *Apium graveolens* Dulce group), entire leaves (e.g., lettuce, *Lactuca sativa*), immature fruits (e.g., cucumber, *Cucumis sativus*), roots (e.g., carrot, *Dacus carota*), and specialized structures such as bulbs (e.g., onion, *Allium cepa* Cepa group) and tubers (e.g., white potato, *Solanum tuberosum*).

Further expanding this already broad definition is the inclusion of mature fruits that are consumed as part of a main meal rather than dessert (e.g., tomato, *Solanum lycopersicum*). This culinary exception to the anatomical rule was given legal precedence in the US Supreme Court decision *Nix v. Hedden* (1893) that confirmed common usage of "vegetable" in reference to tomato. This has since been extended to beans and other fruits. Even dessert melons (e.g., cantaloupe, *Cucumis melo* Cantalupensis group), which are fruits by every botanical, legal, and culinary definition, are frequently "lumped" in with vegetables because of similarities in biology and culture that they share with their more vegetal cousins in the *Cucurbitaceae* (Jeffery 1990) (Table 1.1).

Handbook of Vegetables and Vegetable Processing, Volume I, Second Edition. Edited by Muhammad Siddiq and Mark A. Uebersax.

Table 1.1 Botanical names, common names, and edible parts of select vegetables by family; Families in the Monocotyledons are listed first (shaded) followed by families in Dicotyledons.

Family	Botanical Name	Common Name	Edible Plant Part
***Alliaceae* (Onion family)**			
	Allium ampeloprasum L. Ampeloprasum group	Great-headed garlic	Bulb and leaf
	Allium ampeloprasum L. Kurrat group	Kurrat	Pseudostem
	Allium ampeloprasum L. Porrum group	Leek	Pseudostem and leaf
	Allium cepa L. Aggregatum group	Shallot	Pseudostem and leaf
	Allium cepa L. Cepa group	Onion	Bulb
	Allium cepa L. Proliferum group	Tree onion, Egyptian onion	Aerial bulb
	Allium chinense G. Don.	Rakkyo	Bulb
	Allium fistulosum L.	Welsh onion, Japanese bunching onion	Pseudostem and leaf
	Allium grayi Regel	Japanese garlic	Leaf
	Allium sativum L.	Garlic	Bulb and leaf
	Allium schoenoprasum L.	Chive	Leaf
	Allium scorodoprasum L.	Sand leek, giant garlic	Leaf and bulb
	Allium tuberosum Rottler ex Sprengel	Chinese chive, garlic chive	Leaf, immature flower
	Allium victorialis L. Platyphyllum group, Hult.	Longroot onion, victory onion, Alpine leek	Bulb, leaf
***Araceae* (Arum family)**			
	Alocasia macrorrhiza (L.) Schott	Giant taro, alocasia, giant elephant's ear	Corm, immature leaf, petiole
	Amorphophallus paeoniifolius (Dennst.) Nicolson	Elephant foot yam	Corm
	Colocasia esculenta (L.) Schott	Taro, dasheen, cocoyam	Corm, immature leaf
	Cyrtosperma chamissonis (Schott) Merr.	Giant swamp taro	Corm
	Cyrtosperma merkusii (Hassk.) Schott	Gallan, giant swamp taro	Corm
	Xanthosoma brasiliense (Desf.) Engler	Tannier spinach, Tahitian taro	Immature leaf
	Xanthasomas agittifolium (L.) Schott	Tannia, yellow yautia	Corm and young leaf
***Cyperaceae* (Sedge family)**			
	Cyperus esculentus L.	Yellow nutsedge, rush nut, chufa	Tuber
	Eleocharis dulcis (Burm.f.) Trin. Ex Henschel	Water chestnut, Chinese water chestnut	Corm
	Eleocharis kuroguwai Ohwi	Wild water chestnut	Corm

Table 1.1 (Continued)

Family	Botanical Name	Common Name	Edible Plant Part
Dioscoreaceae **(Yam family)**			
	Dioscorea alata L.	White yam, water yam, purple yam	Tuber
	Dioscorea batatas Decue.	Chinese yam	Tuber
	Dioscorea bulbifera L.	Potato yam, aerial yam	Tuber
	Dioscorea cayenensis Lam.	Yellow yam	Tuber
	Dioscorea dumetorum (Kunth) Pax.	Bitter yam	Tuber
	Dioscorea esculenta (Lour.) Burk.	Lesser yam	Tuber
	Dioscorea rotundata Poir.	White Guinea yam	Tuber
	Dioscorea trifida L. f.	Indian yam	Tuber
Liliaceae **(Lily family)**			
	Asparagus officinalis L.	Asparagus	Shoot
	Hemerocallis spp.	Daylily	Flower
Musaceae **(Banana family)**			
	Musa x paradisiaca L. Paradisiaca group	Plantain	Fruit, flower bud
Poaceae **(Grass family)**			
	Bambusa spp.	Bamboo shoots	Young shoot
	Dendrocalamus latiflorus Munro	Bamboo shoots, Taiwan giant bamboo	Young shoot
	Phyllostachys spp.	Bamboo shoots	Young shoot
	Zea mays L. subsp. *mays*	Sweet corn	Immature kernels and immature cob with kernal
Zingiberaceae **(Ginger family)**			
	Alpinia galanga (L.) Sw.	Greater galangal	Floral sprout and flower, tender shoot, rhizome
	Curcuma longa L.	Tumeric	Rhizome
	Zingiber officinale Roscoe	Ginger	Rhizome and tender shoot
Amaranthaceae **(Amaranth family)**			
	Amaranthus spp.	Amaranthus, tampala	Tender shoot, leaf, sprouted seed
Apiaceae **(Carrot family)**			
	Angelica spp.	Angelica	Tender shoot and leaf
	Anthriscus cerefolium (L.) Hoffm.	Chervil	Leaf
	Apium graveolens L. Dulce group (Mill.) Pers.	Celery	Petiole, leaf

(Continued)

Table 1.1 (Continued)

Family	Botanical Name	Common Name	Edible Plant Part
	Apium graveolens L. Rapaceum group (Mill.) Gaud.	Celeriac, turnip-rooted celery	Root, leaf
	Coriandrum sativum L.	Coriander	Leaf and seed
	Daucus carota L. subsp. *sativus* (Hoffm.) Arcang.	Carrot	Root and leaf
	Foeniculum vulgare	Fennel	Leaf, Petiole
	Pastinaca sativa L.	Parsnip	Root and leaf
	Petroselinum crispum (Mill.) Nym. Crispum group	Parsley	Leaf
	Petroselinum crispum (Mill.) Nym. Tuberosum group	Turnip-rooted parsley	Root and leaf
	Petroselinum crispum (Mill.) Nym. Neapolitanum group	Italian parsley	Leaf
***Asteraceae* (Sunflower family)**			
	Arctium lappa L.	Edible burdock	Root, petiole
	Artemisia dracunculus L. subsp. *sativa* L.	French tarragon	Leaf
	Chrysanthemum spp.	Edible chrysanthemum	Leaf and tender shoot
	Cichorium endivia L.	Endive, escarole	Leaf
	Cichorium intybus L.	Chicory, witloof chicory	Leaf
	Cynara cardunculus L.	Cardoon	Petiole
	Cynara scolymus L.	Globe artichoke	Immature flower bud
	Helianthus tuberose L.	Jerusalem artichoke	Tuber
	Lactuca sativa L. Asparagina group Bailey	Asparagus lettuce, celtuce	Stem
	Lactuca sativa L. Capitata group L.	Head lettuce, butterhead lettuce	Leaf
	Lactuca sativa L. Longifolia group Lam.	Romaine lettuce, leaf lettuce	Leaf
	Taraxacum officinale Wiggers	Dandelion	Leaf, root
	Tragopogon spp.	Salsify	Root and young leaf
***Basellaceae* (Basella family)**			
	Basella alba L.	Indian spinach, Malabar spinach	Leaf and young shoot
***Boraginaceae* (Borage family)**			
	Borago officinalis L.	Borage	Petiole
	Symphytum spp.	Comfrey	Leaf and tender shoot

Table 1.1 (Continued)

Family	Botanical Name	Common Name	Edible Plant Part
***Brassicaceae* (Mustard family)**			
	Armoracia rusticana Gaertn., Mey., Scherb.	Horseradish	Root, leaf, sprouted seed
	Brassica carinata A. Braun	Abyssinian mustard, Ethiopian kale	Leaf
	Brassica juncea (L.) Czernj. & Coss.	Mustard greens	Leaf
	Brassica napus L. Napobrassica group (L.) Reichb.	Rutabaga	Root and leaf
	Brassica napus L. Napus group	Vegetable rape	Leaf and young flower stalk
	Brassica napus L. Pabularia group (DC.) Reichb.	Siberian kale, Hanover salad	Leaf
	Brassica nigra L. Koch.	Black mustard	Leaf
	Brassica oleracea L. Acephala group DC.	Kale, collards	Leaf
	Brassica oleracea L. Alboglabra group Bailey	Chinese kale	Young flower stalk and leaf
	Brassica oleracea L. Botrytis group L.	Cauliflower	Immature floral stalk
	Brassica oleracea L. Capitata group L.	Cabbage	Leaf
	Brassica oleracea L. Costata group DC.	Portuguese cabbage, tronchuda cabbage	Leaf and inflorescence
	Brassica oleracea L. Gemmifera group Zenk.	Brussels sprouts	Axillary bud
	Brassica oleracea L. Gongylodes group L.	Kohlrabi	Enlarged stem
	Brassica oleracea L. Italica group Plenck.	Broccoli	Immature flower stalk
	Brassica oleracea L. Sabauda group L.	Savoy cabbage	Leaf
	Brassica perviridis Bailey	Spinach mustard, tendergreen mustard	Leaf
	Brassica rapa L. Chinensis group (Rupr.) Olsson	Pak choi, Chinese mustard, bok choy	Leaf
	Brassica rapa L. Narinosa group (Bailey) Olsson	Broad-beaked mustard	Leaf
	Brassica rapa L. Parachinensis group (Bailey) Tsen & Lee	Mock pak choi, choy sum	Leaf

(Continued)

Table 1.1 (Continued)

Family	Botanical Name	Common Name	Edible Plant Part
	Brassica rapa L. Pekinensis group (Lour.) Olsson	Chinese cabbage, pe-tsai	Leaf
	Brassica rapa L. Rapa group (DC.) Metzg.	Turnip	Enlarged root
	Brassica rapa L. Utilis group (DC.) Metzg.	Turnip green	Leaf
	Brassica rapa L. Septiceps group (DC.) Metzg.	Turnip broccoli, broccoli raab	Inflorescence
	Eruca sativa Miller	Rocket salad, arugula	Leaf
	Lepidium sativum L.	Garden cress	Leaf
	Nasturtium officinale R. Br.	Watercress	Leaf
	Raphanus sativus L. Caudatus group	Rat-tail radish	Immature seed pod
	Raphanus sativus L. Radicula group	Radish	Root
	Raphanus sativus L. Daikon group	Daikon	Root
	Sinapis alba L.	White mustard	Leaf and young flower stalk
	Wasabia japonica (Miq.) Matsum.	Wasabi, Japanese horseradish	Rhizome, young shoot
***Chenopodiaceae* (Goosefoot family)**			
	Atriplex hortensis L.	Orach	Leaf
	Beta vulgaris L. Cicla group	Chard, Swiss chard	Leaf
	Beta vulgaris L. Crassa group	Garden beet	Root and leaf
	Chenopodium quinoa Willd.	Quinoa	Leaf
	Spinacia oleracea L.	Spinach	Leaf
***Convolvulaceae* (Bindweed family)**			
	Ipomoea aquatica Forssk.	Water spinach, kangkong	Tender shoot and leaf
	Ipomoea batatas (L.) Lam.	Sweet potato	Root and leaf
***Cucurbitaceae* (Gourd family)**			
	Benincasa hispida (Thunb.) Cogn.	Wax gourd	Immature/mature fruit
	Citrullus lanatus Lantanus group (Thunb.) Matsum & Nakai	Watermelon	Ripe fruit and seed
	Citrullus lanatus Citroides group (Bailey) Mansf.	Citron, preserving melon	Fruit
	Cucumis anguria L.	West Indian gherkin	Immature fruit

Table 1.1 (Continued)

Family	Botanical Name	Common Name	Edible Plant Part
	Cucumis melo L. Cantalupensis group	Cantaloupe	Fruit
	Cucumis melo L. Flexuosus group	Japanese cucumber, snake melon	Immature fruit
	Cucumis melo L. Inodorus group	Honeydew melon, casaba melon	Fruit
	Cucumis melo L. Reticulatus group	Muskmelon (cantaloupe), Persian melon	Ripe fruit
	Cucumis metuliferus E. Meyer ex Naudin	African horned cucumber	Fruit
	Cucumis sativus L.	Cucumber	Immature fruit
	Cucurbita argyrosperma Huber	Pumpkin	Young/mature fruit and seed
	Cucurbita maxima Duchesne	Giant pumpkin, winter squash	Mature fruit and seed
	Cucurbita moschata Duchesne	Butternut squash, tropical pumpkin	Young and mature fruit
	Cucurbita pepo L.	Summer squash, zucchini	Young fruit
	Cucurbita pepo L.	Common field pumpkin	Mature fruit and seed
	Lagenaria siceraria (Mol.) Standl.	Bottle gourd, calabash gourd	Immature fruit, tender shoot, and leaf
	Luffa spp.	Loofah	Immature fruit
	Momordica charantia L.	Bitter gourd, balsam pear	Immature fruit and young leaf
	Sechium edule (Jacq.) Swartz.	Chayote, vegetable pear	Fruit, tender shoot, leaf
***Euphorbiaceae* (Spurge family)**			
	Manihot esculenta Crantz	Yucca, cassava, manioc	Root and leaf
	Sauropus androgynus (L.) Merr.	Common sauropus	Leaf
***Fabaceae* (Pea family)**			
	Arachis hypogaea L.	Peanut, groundnut	Immature/mature seed
	Bauhinia esculenta Burchell	Marama bean	Immature pod and root
	Cajanus cajan (L.) Huth.	Cajan pea, pigeon pea	Immature pod/leaf
	Canavalia ensiformis (L.) DC.	Jack bean, horse bean	Immature seed
	Canavalia gladiata (Jacq.) DC.	Sword bean, horse bean	Immature seed
	Cicer arietinum L.	Garbanzo, chickpea	Seed
	Glycine max (L.) Merr.	Soybean	Immature and sprouted seed

(Continued)

Table 1.1 (Continued)

Family	Botanical Name	Common Name	Edible Plant Part
	Lablab purpurus (L.) Sweet.	Hyacinth bean	Immature seed
	Lens culinaris Medikus	Lentil	Immature pod, sprouted seed
	Lupinus spp.	Lupin	Seed
	Neptunia oleracea Lour.	Water mimosa	Leaf and tender shoot
	Pachyrhizus erosus (L.) Urban	Jicama, Mexican yam bean	Root, immature pod, seed
	Phaseolus acutifolius A. Gray	Tepary bean	Seed, immature pod
	Phaseolus coccineus L.	Scarlet runner bean	Immature pod and seed
	Phaseolus lunatus L.	Lima bean	Immature seed, mature seed
	Phaseolus vulgaris L.	Garden bean, snap bean	Immature pod and seed
	Pisum sativum L. Sativum group	Pea, garden pea	Immature seed, tender shoot
	Pisum sativum L. Macrocarpon group	Edible-podded pea	Immature pod
	Pisum sativum L. Saccharatum group	Snow pea, China pea	Immature seed, tender shoot
	Psophocarpus tetragonolobus (L.) DC.	Goa bean, winged bean	Immature pod, seed, leaf, root
	Pueraria lobata (Willd.) Ohwi	Kudzu	Root, leaf, tender shoot
	Tetragonolobus purpureus Moench	Asparagus pea, winged pea	Immature pod
	Trigonella foenum-graecum L.	Fenugreek	Leaf, tender shoot, immature pod
	Vicia faba L.	Fava bean, broad bean, horse bean	Immature seed
	Vigna aconitifolia (Jacq.) Marechal	Moth bean	Immature pod and seed
	Vigna angularis (Willd.) Ohwi & Ohashi	Adzuki bean	Seed
	Vigna mungo (L.) Hepper	Black gram, urad bean	Immature pod and seed
	Vigna radiata (L.) Wilcz.	Mung bean	Immature pod, sprouted seed, seed
	Vigna subterranea (L.) Verdn.	Madagascar groundnut	Immature/mature seed
	Vigna umbellata (Thunb.) Ohwi & Ohashi	Rice bean	Seed
	Vigna unguiculata (L.) Walp. Sesquipedalis group (L.)	Asparagus bean, yard-long bean, cowpea	Immature pod and seed
	Vigna unguiculata (L.) Walp. Unguiculata group (L.)	Southern pea, cowpea	Immature pod and seed

Table 1.1 (Continued)

Family	Botanical Name	Common Name	Edible Plant Part
***Lamiaceae* (Mint family)**			
	Mentha spicata L. em. Harley	Spearmint	Leaf and inflorescence
	Ocimum basilicum L.	Common basil, sweet basil	Leaf
	Ocimum canum Sims.	Hoary basil	Young leaves
	Origanum vulgare L.	Oregano, marjoram	Flowering plant and inflorescence
	Perilla frutescens (L.) Britt. Crispa group (Thunb.) Deane	Perilla	Leaf and seed
***Malvaceae* (Mallow family)**			
	Abelmoschus esculentus (L.) Moench	Okra, gumbo	Immature fruit
	Hibiscus sabdariffa L.	Jamaican sorrel, roselle	Calyx and leaf
***Moringacea* (Moringa family)**			
	Moringa oleifera L.	Horseradish tree	Leaf, pods, flowers
***Nelumbonaceae* (Lotus root)**			
	Nelumbo nucifera Gaertn.	Lotus root	Rhizome, leaf, seed
***Polygonaceae* (Buckwheat family)**			
	Rheum rhabarbarum L.	Rhubarb, pieplant	Petiole
	Rumex spp.	Sorrel	Leaf
***Portulacaceae* (Purslane family)**			
	Portulaca oleracea L.	Purslane	Leaf and young shoot
***Solanaceae* (Nightshade family)**			
	Capsicum annuum L. Grossum group	Bell pepper	Fruit
	Capsicum annuum L. Longum group	Cayenne pepper, chili pepper	Mature fruit
	Capsicum chinense Jacq.	Scotch bonnet, datil, habanero pepper	Fruit
	Capsicum frutescens L.	Tabasco pepper, chili pepper	Fruit
	Physalis ixocarpa Brot. ex Hornem.	Tomatillo	Unripe fruit
	Physalis peruviana L.	Cape gooseberry, Peruvian groundcherry	Ripe fruit
	Solanum lycopersicum Mill.	Tomato	Ripe fruit
	Solanum pimpinellifolium (L.) Mill.	Currant tomato	Ripe fruit
	Solanum melongena L.	Eggplant, aubergine	Immature fruit

(Continued)

Table 1.1 (Continued)

Family	Botanical Name	Common Name	Edible Plant Part
	Solanum muricatum Ait.	Pepino, sweet pepino	Ripe fruit
	Solanum tuberosum L.	Potato	Tuber
***Tropacolaceae* (Nasturtium family)**			
	Tropaeolum majus L.	Nasturtium	Leaf, flower

Source: Abridged and modified from Maynard and Hochmuth (2007).

The biological diversity among vegetables necessitates a systematic method for grouping vegetables in order to efficiently access information and make management decisions. Understanding the biology of vegetable crops will aid decision making associated with production, postharvest handling, and marketing (Maynard and Hochmuth 2007). Ultimately, vegetable classification is inextricably linked with crop biology. Three basic approaches toward classification of vegetables that are based on commonalities among groups are as follows:

1) Tissues and organs consumed
2) Ecological adaptation
3) Taxonomy

All three approaches toward classification are based on some level of commonality in crop biology, with the precision of classification varying from relatively low (plant part consumed) to very high (taxonomic). Table 1.2 is a glossary of selected terms related to vegetable anatomy, biology, and classification.

Vegetable Tissues and Organs

The phenotypic diversity among vegetables is actually based on relatively few types of specialized cells and tissues. Dermal, ground, and vascular tissue make up the three basic tissue systems. Ultimately, the structure of these cells and tissues determine their function.

Dermal Tissues

Epidermal cells, together with cutin and cuticular waxes, make up the outer layers of leaves, fruit, and other above-ground structures and protect against water loss and other adverse abiotic and biotic factors. The periderm (cork) layer of mature roots and stems is analogous to the epidermis, but consists of nonliving cells supplemented with suberin. Stomatal guard cells are epidermal cells specialized in regulating gas exchange, and are especially dense on the abaxial surface of leaves. Lenticels are specialized, unsuberized dermal structures (appearing as raised dots or bumps) that regulate gas exchange on roots, stems, and fruits. Trichomes and root hairs are dermal cells with excretory, absorptive, and other functions critical to the ecology of vegetables.

Ground Tissues

Ground tissues are composed of the parenchyma, collenchyma, and sclerenchyma. Parenchyma cells are thin-walled cells that make up much of the ground tissues of vegetables. Parenchyma cells often serve to store starch and other compounds. The cortex and pith of white potato are examples of ground tissues dominated by parenchyma. Collenchyma cells have alternating thin and thick cell walls that provide flexible support for stems, as in the strings of celery (*Apium graveolens*). Sclerenchyma tissues include sclerids and fibers with tough cell

Table 1.2 Glossary of selected terms relating to vegetable anatomy, biology, and classification.

Term	Definition
Andromonoecious	Staminate and hermaphrodite flowers on same plant
Annual	Plant that completes life cycle (sets seed) and dies in one year
Axillary bud	Bud occurring in the leaf axil, as in Brussels sprouts
Berry	Fruit fleshy throughout
Biennial	Plant that completes life cycle (sets seed) and dies in two years
Bolt	Develops inflorescence prematurely, as in lettuce and spinach
Bract	Modified leaf or scale at base of flower
Bulb	Bud surrounded by fleshy and papery scales attached to stem plate
Calyx	Sepals or outer whorl of perianth
Carpel	Individual unit of compound pistil
Caryopsis	Fruit (grain) of grass, as in sweet corn
Corm	Vertically oriented fleshy, solid stem at or below soil surface (e.g., taro)
Cortex	Storage tissues of root or stem, between epidermis and vascular tissue
Cultivar	Group of cultivated plants with distinguishing characteristics that are retained when plants are reproduced
Curd	Fleshy inflorescence with flower buds undifferentiated (e.g., cauliflower)
Determinant	Branch stops growing at flowering
Dioecious	Staminate (male) and pistillate (female) flowers on separate plants
Endocarp	Inner layer of fleshy fruit wall
Endodermis	Inner layer of cortex, adjacent to vascular tissue
Epidermis	Thin outer layer of leaf, stem, or root
Exocarp	Outermost layer (e.g., rind or skin) of fruit wall
Floret	Small flower on inflorescence (e.g., artichoke)
Fruit	Mature ovary
Gynoecious	Producing predominantly, or only, female flowers
Indeterminant	Branch continues to grow after flowering starts
Legume	Single carpel fruit with two sutures, seed attached along one suture
Lenticel	Raised, unsuberized dot or pore for gas exchange
Mesocarp	Middle layer of pericarp or fruit wall
Locule	Seed cavity of fruit; also, compartment of ovary or anther
Midrib	Pronounced central vein of leaf
Monoecious	Male and female flowers on same plant
Node	Enlarged area on stem where buds emerge
Pedicel	Stalk or stem of individual flower or floret

(Continued)

Table 1.2 (Continued)

Term	Definition
Peduncle	Primary flower stalk of inflorescence
Pepo	Cucurbit fruit, leathery or woody exocarp inseparable from endocarp
Perfect flower	Flower with both male and female parts
Pericarp	Fruit wall
Perennial	Plants persisting for three years or more
Petiole	Leaf stalk
Rhizome	Horizontally oriented underground stem modified for storage, with nodes capable of forming new roots and shoots
Scales	Fleshy or dry modified leaves of a bulb
Silique	Specialized fruit of *Brassicaceae*, with two fused carpels
Stele	Central core of vascular strengthening tissue in roots and stems
Tuber	Fleshy, enlarged stems occurring at end of rhizomes

walls. Sclerenchyma cells are typically scarce in edible vegetable organs, but are important components of seed coats, nutshells, and the stony endocarps of peaches (*Prunus persica*) and related fruits.

Conducting Tissues

Vascular tissues conduct water, minerals, photosynthates, and other compounds throughout the plant. The xylem is part of the apoplast and consists primarily of nonliving tracheids and vessel elements. The xylem transports water, mineral nutrients, and some organic compounds, generally from the roots to leaves. The phloem is part of the symplast, consists primarily of sieve cells and companion cells, and is important in conducting sugars, amino acids, and other compounds from source (usually leaves) to sink (actively growing meristems, roots, developing fruits, and seeds). Both xylem and phloem are supported by parenchyma cells and fiber. Some xylem cells (i.e., tracheids) have thickened cell walls that contribute significantly to the structural support of tissues.

The differentiation and variable structure of plant tissues result in diverse functions among the plant organs (stems, roots, and leaves) and organ systems (e.g., fruits, flowers, buds, and bulbs) consumed as vegetables.

Classification of Vegetables

The classification of vegetables by edible parts has been termed "Supermarket Botany" (Graham et al. 2006). Although broad and not always anatomically correct, the grouping of commodities as leafy, fruit, and root vegetables has value to growers, distributors, and others in the market chain because of similarities in cultural and postharvest requirements within groups. In addition to being practical, the division of vegetables by anatomical structure highlights the impressive crop improvement accomplishments of the early agriculturalists, which both exploited and expanded the structural diversity inherent in the plant kingdom.

Leafy Vegetables

Leaves are the primary site of photosynthesis in plants and are generally the most nutrient dense and most perishable of the vegetables. Leaves, particularly dark green leaves, contain relatively high levels of minerals (e.g., Fe, Mg, Ca), enzymes (protein), and secondary metabolites (e.g., carotenes and xanthophylls). These compounds, important to human nutrition, are required by the plant for light collection, electron transport, photoprotection, carbon fixation, and many other biochemical processes abundant in leaves. Stomata are especially dense on the abaxial surface of leaves and are the terminal point of transpiration, which is the primary mechanism for dissipating heat accumulated from intercepting solar radiation. High stomatal density combined with the high surface area make leafy vegetables more susceptible to postharvest water loss than other vegetables. Subsequently, rapid cooling after harvest and storage under high humidity are particularly important postharvest procedures for leafy vegetables (Siddiqui, 2015; Pareek, 2016).

Leafy vegetables are concentrated in the *Asteraceae* (*Compositae*), *Brassicaceae* (*Cruciferae*), and *Chenopodiaceae*. Culinary herbs, dominated by the *Lamiaceae* (*Labiatae*), are also categorized as leafy vegetables. Other vegetables consumed primarily for leaf structures include *Ipomoea aquatica* (*Convolvulaceae*), celery (*Apiaceae*), and amaranthus (*Amaranthaceae*). The leaves of many plants grown primarily for other organs (fruits, roots, specialized structures) are often utilized to supplement the diet. The leaves of taro (*Colocasia esculenta*) and cassava (*Manihot esculenta*), as well as the young leaves and shoots of sweet potato (*Ipomoea batatas*) and many cucurbits (*Cucurbitaceae*) are typical examples of vegetables in this category.

Leafy vegetables that are generally cooked before consumption to soften texture and improve flavor (e.g., mature leaves of many *Brassica* spp. and *Chenopodiaceae*) are sometimes classified as “greens” to differentiate them from leafy vegetables that that are consumed raw, often as salad (e.g., most *Compositae* and the very young leaves of many *Brassica*). “Potherb” is used to describe greens used in small quantity for flavoring in cooking.

While generally softer and lighter in flavor than cooking greens, salad crops vary in their texture and flavor, and these differences are important in differentiating among leafy vegetables consumed raw. Examples include textural differences among lettuce (crisphead vs. butterhead types) and variable levels of texture and pungency in species used in mesclun mixes. Textural and flavor differences are caused by variability in leaf structure (cuticle thickness), cell type, succulence, as well as type and quantity of phytochemicals (e.g., glucosinolates) present (Figure 1.1).

Root Vegetables

Root vegetables include true roots (carrot, sweet potato, and cassava) as well as specialized structures such as tubers, bulbs, corms (e.g., taro), and hypocotyls (e.g., radish, *Raphanus sativus*). These specialized structures are classified as root vegetables because of their full or partial subterranean habit, their physical proximity to true roots, and their function as storage organs for starch and other compounds. Most of these specialized structures consist primarily of stem tissue, with bulbs being a notable exception. Although significant variability in caloric value and shelf life exists within the roots crops, they are typically higher in calories and less perishable than other vegetables due to their storage function, suberized periderm or protective skin, and high dry matter content (Figure 1.2).

True Roots

The biology and anatomy of true root vegetables are exemplified by a comparison of three

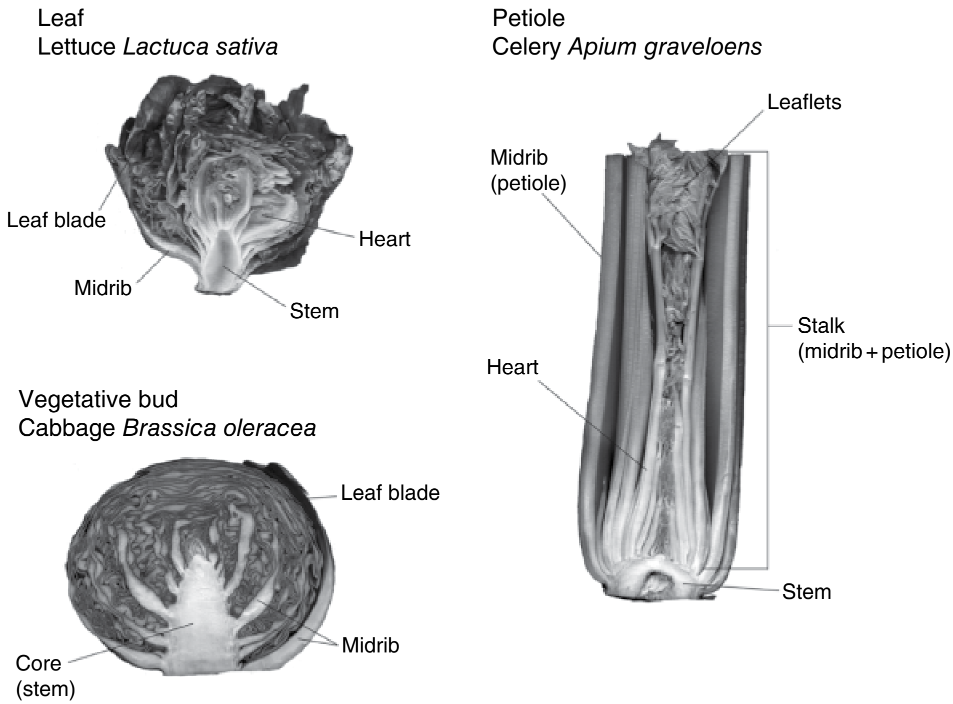

Figure 1.1 Anatomy of select leafy vegetables.

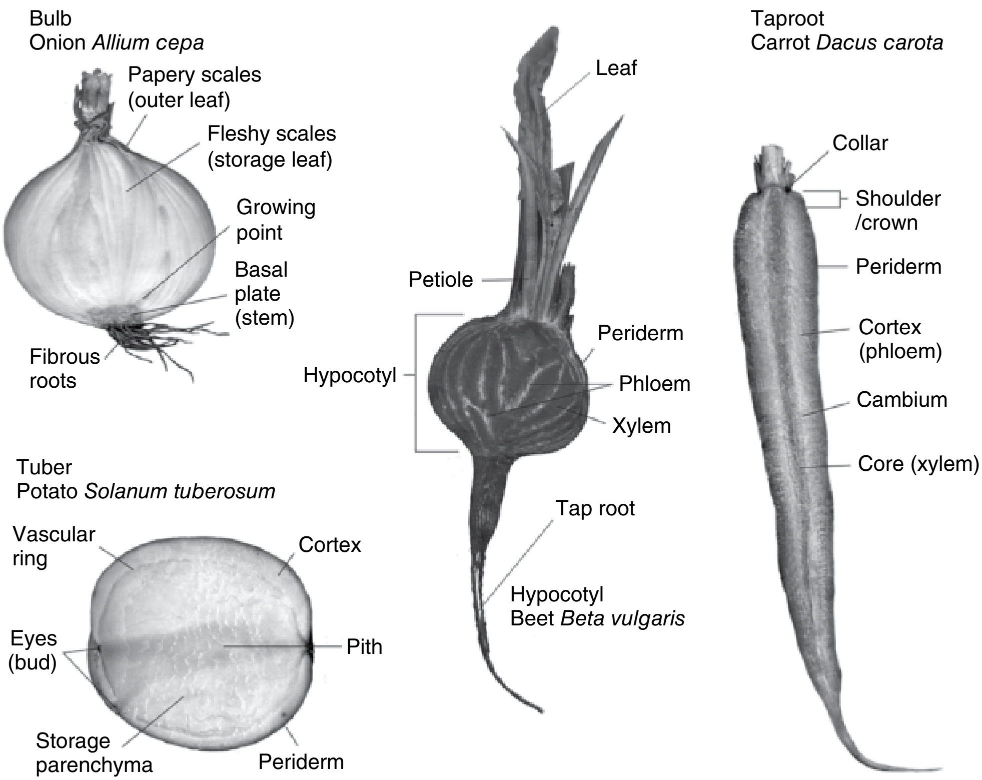

Figure 1.2 Anatomy of select vegetables classified as root crops.

important crops: carrot, sweet potato, and cassava. All true roots consist of secondary vascular tissue arising from a cambial layer, with phloem (cortical) tissue extending outward and xylem tissue inward. Secondary plant products are found throughout root tissues, but many are particularly abundant in the pericycle, which is closely associated with the periderm and is removed upon peeling.

In carrots (a primary tap root), the majority of the edible portion is composed of sugar-storing parenchyma associated with secondary phloem tissue. Sucrose is the dominant sugar in mature roots, and roots contain little starch. The tissue associated with the secondary xylem in the center of roots (pith) is of coarser texture, and small pith is desirable in commercial carrots (Rubatzky and Yamaguchi 1997). In contrast, the majority of the edible portions of sweet potato and cassava are internal to the vascular ring of enlarged secondary roots and consist of starch-containing storage parenchyma, which surround a matrix of xylem vessels. In cassava, all cortical tissue is removed along with the periderm (collectively, the peel) prior to cooking, and a dense bundle of fibrous vascular tissue in the center of roots is also removed before consumption. Although the majority of sweet potato and cassava starch is amylopectin, variation in the minority quantity of amylose affects texture of the cooked product. Glutinous texture, stickiness, or waxiness of the product increases with a decreasing ratio of amylose to amylopectin.

Modified Stems

Tubers are enlarged, fleshy underground stems that share some of the characteristics of true roots, including development underground, a suberized periderm, and starch-storing parenchyma. The best-known vegetable examples of tubers are the white potato and the yams (*Dioscorea* spp.).

Potato tubers form at the end of rhizomes originating from the main stem. Recessed buds (eyes) and leaf scars (eyebrows) on the skin surface are conspicuous indicators that the potato is derived from stem rather than root tissue (Figure 1.2). In the absence of dormancy or chemical inhibition, these buds will sprout and allow for the vegetative reproduction of potato from "seed" pieces or small whole potatoes. In contrast to potato, yam tubers lack conspicuous buds, leaf scars, and other outward signs of being derived from stem tissue. Sprouts will form from yam tubers and tuber pieces, but generate most readily from the proximal end of tubers. As with true roots, cooking quality of tubers is influenced by starch type, dry matter content, and cell size.

The swollen hypocotyl tissues of table beet (*Beta vulgaris* group Crassa) and radish (*Rhaphanus sativus*) are closely associated with the taproot, and the edible portion is described as the hypocotyl-root axis. The multiple cambia and differentially pigmented vascular tissues in beets result in the characteristic banding observed in cross sections of the vegetable (Figure 1.2).

Corms are a third type of modified stem grouped with the root vegetables and are exemplified by taro (*Colocasia esculenta*) and other members of the *Araceae*. Corms are vertically oriented, apically dominant, compressed starchy stem bases that initiate underground but continue to grow partially above ground. Adventitious shoots eventually arise from the parent corm to form secondary corms or cormels.

Bulb vegetables, mainly in the *Alliaceae*, are composed primarily of swollen, fleshy leaves (scales) specialized for storage of carbohydrates and other compounds (Figure 1.2). These leaves arise in a whorl from a compressed conical stem called a basal plate. Dry, papery scales of the bulb exterior protect the bulb.

Fruit Vegetables

Fruit vegetables are concentrated in the *Solanaceae*, *Cucurbitaceae*, and *Fabaceae*, but occur in other families as well. Large fruited annual vegetables of the *Cucurbitaceae* and *Solanaceae* are generally warm and hot season crops because their wild progenitors evolved in tropical and subtropical latitudes where growing seasons are long enough to produce enough vegetative growth to support large fruits in a single year (see the following section on ecological adaptation). Other vegetables in this group are okra (*Abelmochus esculentus*) and beans (*Phaseolus* spp.). Intensive selection has since resulted in early cultivars of most fruiting vegetables that will produce fruit in the short growing periods of northern latitudes.

Among the commercial vegetables, simple fruits dominate. Berry, pepo, and legume are the characteristic fruit types of the *Solanaceae*, *Cucurbitaceae*, and *Fabaceae*, respectively. Specialized pods produced by okra (capsule) and the *Brassicaceae* and *Morigaceae* (silique) are dry and at least partially dehiscent at maturity but are consumed immature green, while still succulent. Each kernel on an ear of corn is a simple indehiscent fruit (caryopsis) (Figure 1.3).

In many fruit vegetables, the whole fruit is edible, although not necessarily consumed.

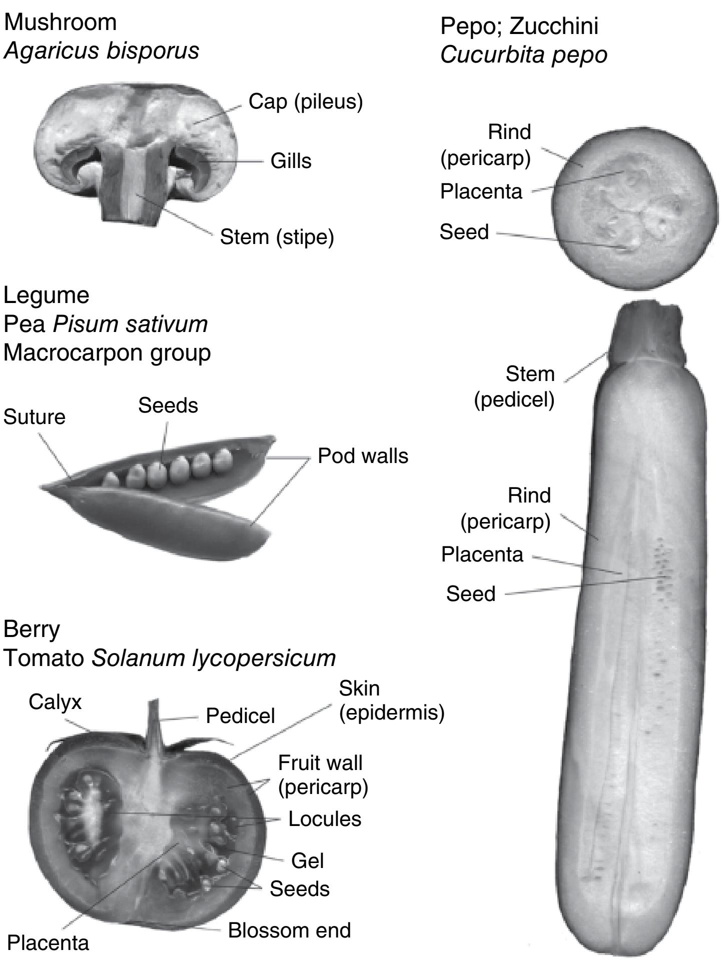

Figure 1.3 Anatomy of select vegetables composed of fruits and fruiting bodies (mushroom).

For example, the entire pericarp—along with placenta and other tissue—of tomatoes, eggplants (*Solanum melogena*), cucumbers, and other vegetables is consumed. These vegetables may also be peeled to soften texture and lighten flavor by removing toughened dermal cells as well as cutin, waxes, and other secondary metabolites that are associated with organ protection, and which are concentrated in the epidermis and outer pericarp (exocarp). Immature fruit of bittermelon (*Momordica charantia*) may also be peeled to reduce bitterness caused by momordicosides and other compounds concentrated in the outer pericarp, while the tough endocarp and spongy placenta of bittermelon are discarded along with the seeds. The edible portion of mature *Cucurbita* fruit is pericarp tissue. In *Cucumis melo* (e.g., cantaloupe and muskmelon), the most internal portions of the pericarp (endocarp and mesocarp) are eaten, with the leathery rind (exocarp and some mesocarp) discarded. In watermelon (*Citrullus lanatnus*), the rind includes much of the pericarp, with placental tissue making up a substantial portion of what is consumed, although succulent parts of the rind can be pickled and otherwise prepared.

Other Vegetables

Other vegetables primarily comprising stem material include stem lettuce (*Lactuca sativa*), kohlrabi (*Brassica oleracea* Gongyloides group), asparagus (*Asparagus officinalis*), bamboo shoot (*Poaceae*), and heart-of-palm (*Araceae*). Also, flowers of many plant taxa are consumed either raw or cooked. Important vegetables comprise floral structures include broccoli and globe artichoke (*Cynara scolymus*) (Figure 1.4).

Ecological Adaptation of Vegetables

The environmental optima (e.g., temperature, light, and soil moisture) of vegetable crops will depend greatly on the center of origin of their wild progenitors. For example, vegetables whose center of origin lies in the tropics are often generally classified as warm-season, short-day plants. In contrast, crops with temperate origins are often considered cool-season, long-day plants. Our need for food and fiber has resulted in strong, artificial selection pressure for broad adaptability in many vegetable crops (Wien 1997; Sung et al. 2008). Nevertheless, many vegetables can be grouped with regard to their environmental requirements, and knowledge of these requirements is critical for crop managers to make effective decisions (Table 1.3).

Temperature

Classification of vegetable crops by temperature is based on three sets of values, or cardinal temperatures, that describe the minimum, maximum, and optimum temperature ranges for crop growth. Minimum and maximum temperatures represent the limits at which growth and development are thought to stop or at least slow to a negligible rate, while plant growth and normal development are most rapid within the optimum temperature range. Krug (1997) stratifies the simple classification of “warm” and “cool” season crops to account for subtle but significant differences in cardinal temperatures. For example, the effective growth range for hot-season crops does not include temperatures as low as the minima for warm-season crops, while heat-tolerant cool crops have temperature maxima that exceed those of other cool-season crops.

A practical application resulting from the dominant influence of temperature on vegetable crop biology is the use of a heat unit system (or temperature sum concept) to predict plant growth. The most simple and often cited example is that used to predict harvest dates for corn. Daily heat units (HU) accumulated are often calculated using the equation $HU = \Sigma (T_{avg} - T_{base})$, where T_{avg} is the average daily temperature and T_{base} is the minimum temperature for the crop, below which no growth is expected.

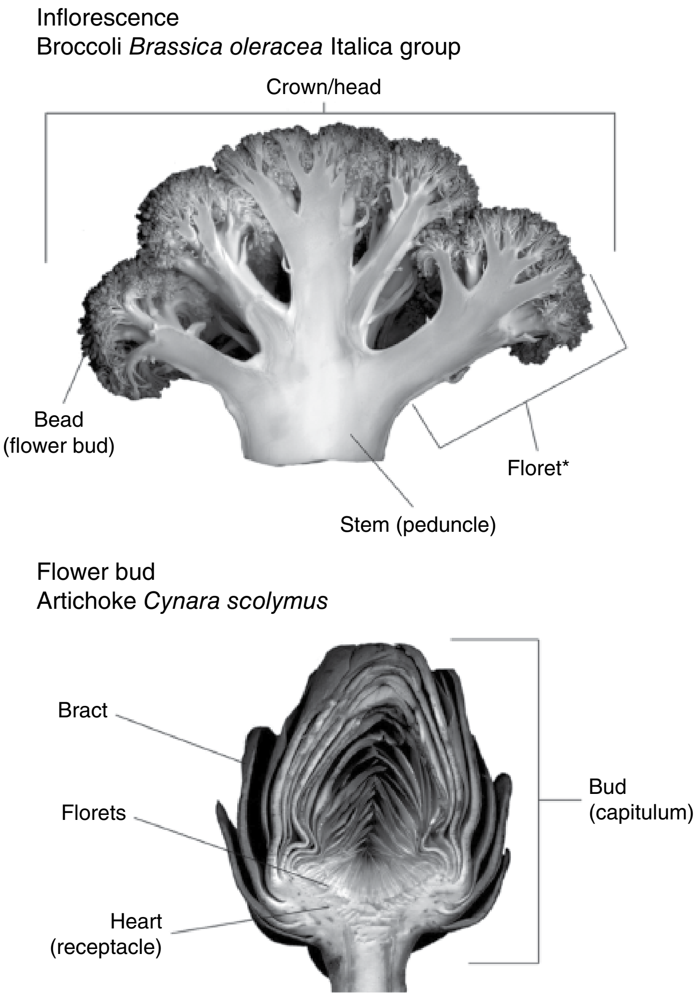

Figure 1.4 Anatomy of select vegetables composed of flowers and associated structures. Asterisk (*) indicates “floret” used as an industry designation for individual branches of inflorescence in broccoli.

Cool-season crops grown during the summer in temperate zones will frequently be exposed to supra-optimal temperatures, and HU calculations must account for the negative effect of high temperatures on crop growth. In head cabbage, HU calculations using upper and lower threshold temperatures of 21 °C and 0 °C have been used effectively to explain seasonal variability in head size and weight (Radovich et al. 2004; Figure 1.5). If the daily maximum temperature (T_{max}) falls below the upper threshold, then HU are calculated as described above for corn. If T_{max} exceeds 21 °C, then an intermediate cutoff method is employed, where $HU = [(T_{min} + 21)/2)] - [(T_{max} - 21) \times 2]$. Using this cutoff method, HU = 0 when $T_{max} \geq 30$ °C.

Unfortunately, single-factor models such as HU are not adequate to predict all developmental

Table 1.3 Classification of vegetables based on life cycle, temperature growth requirements, and photoperiodicity.

Classification	Examples
Life cycle	
Perennial	*Asparagus officinale, Capsicum* spp., *Ipomoea batatas, Solanum* sp.
Biennial	*Beta vulgaris, Brassica oleracea* Capitata group, *Dacus carota*
Annual	*Spinacia oleracea, Cucurbita* spp., *Brassica oleracea* Italica group
Temperature demand* (temperature range for effective growth)	
Hot (18°–35 °C)	*Abelmochus esculentus, Citrullus lanatus, Capsicum chinense*
Warm (12°–35 °C)	*Cucumis sativus, Cucurbita* spp., *Zea mays, Capsicum annuum*
Cool (heat tolerant) (7°–30 °C)	*Colocasia escultenta, Allium* spp., *Cynara scolymus, Brassica rapa L.* Chinensis group
Cool (7°–25 °C)	*Brassica oleracea, Raphanus sativus, Latuca sativa, Solanum tuberosm*
Photoperiod	
Short day	*Amaranthus* spp., *Pachyrhizus erosus, Solanum tuberosum*
Day neutral	*Solanum lycopersicum, Phaseolus* spp., *Cucurbita* spp.
Long day	*Allium cepa* Cepa group, *Spinacia oleracea*

Source: Adapted from Pierce (1987), *Krug (1997).

events. In the cabbage example, for example, variation in HU fails to explain year-to-year variability in head density. Similarly, while estimation of head density changes in lettuce is improved by including light intensity into the HU equation (i.e., photothermal units), the inclusion of an additional factor is not adequate to satisfactorily predict density changes (Jenni and Bourgeois 2008). This highlights the potentially complex relationship between ontogeny and environmental factors.

Although heat drives vegetative growth in most vegetables, a certain number of cold units (time of exposure to temperatures below some critical minimum) are required to initiate flowering in many temperate biennial vegetables. This phenomenon, termed *vernalization*, is exhibited by *Brassica*, beets, and other vegetables. In crops that are insensitive to photoperiod, cold units may be calculated similarly as described above, while photothermal units are employed for photoperiodic crops (Searle and Reid 2016).

Light

All plants require light for photosynthesis. While a degree of shading will improve the growth of some vegetables, this is often a temperature response to cooling resulting from reduced solar radiation. In addition, while the quality (i.e., wavelength) of light significantly affects crop phenology, light quantity (intensity and daylength) generally impacts vegetable crops in a similar manner. However, crops often differ substantially in their response to photoperiod (Bian et al. 2015).

As a rule, plants exhibit some sensitivity to photoperiod in their development, particularly with regard to flowering and storage organ development (Waycott 1995; Martinez-Garcia et al. 2002).

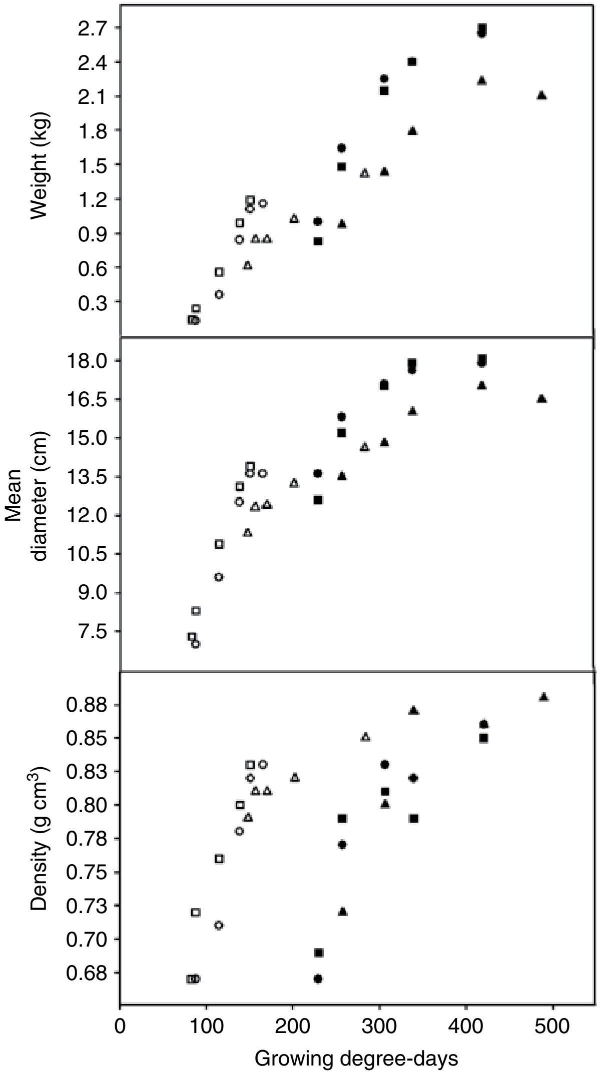

Figure 1.5 Relationship between growing degree-days and head traits of cabbage (*Brassica oleracea* Capitata group) grown in 2001 (full symbols) and 2002 (open symbols) at the Ohio Agricultural Research and Development Center. Treatment means of cultivars "Bravo," "Bronco," and "Transam," are represented by circles, squares, and triangles, respectively (from Radovich et al. 2004).

As mentioned previously, tropical and temperate crops are frequently considered short- and long-day plants, respectively, although the actual stimulus is the duration of the dark period, and day neutral cultivars have been developed for many crops. Short-day crops include yams, beans, cowpeas, sweet potatoes, and potatoes. Onions, lettuce, and spinach are examples of long-day vegetables (Mettananda and Fordham 1997).

Taxonomy of Vegetables

Botanical classification is the most precise and ultimately most useful method of organizing plants by biological commonality. The vast majority of vegetables are angiosperms (subclass monocotyledons and dicotyledons) in the division Spermophyta. The Tallophyta (algae and fungi) are also important.

The broadest taxonomic grouping relevant to vegetable production and management is the family. Similarities in structure and adaptation among plants within families are generally conspicuous enough to be useful in olericulture. For example, ecological and physiological differences among families are often adequate enough to be resistant to many of each other's specific pathogens. A practical application of this by crop managers is to avoid successive planting of crops from the same family when designing vegetable rotations in production.

Subordinate to the family is genus, followed by the species designation. Members of a species are usually genetically isolated from those of other species, and can freely interbreed with individuals from the same species. Biological differences tend to be minor below the species level, but infra-specific variability in vegetable morphology and ecological adaptation is relevant enough to warrant further classification.

Significant confusion and a lack of consistency in vegetable nomenclature at the subspecific level centers on three terms: subspecies, *varietas*, and group. All are categories of vegetables sharing distinct features of functional relevance and have been used interchangeably. Subspecies and *varietas* are botanical terms, while group is used exclusively by horticulturalists. The differences between subspecies (ssp.) and *varietas* (also variety, var.) have been recognized as subtle but distinct, with the latter subordinate to the former (Kapadia 1963). However, by current convention, the terms are used interchangeably, with ssp. more frequently used in Europe and var. more common in the United States (Hamilton and Reichard 1992).

Characteristics that distinguish ssp. and var. are expected to go beyond the morphological and have geographic, ecologic, or evolutionary integrity (Hamilton and Reichard 1992). In contrast, horticultural groups may be defined exclusively by functional similarities in morphology, as governed by the International Code of Nomenclature for Cultivated Plants (ICNCP or Cultivated Plant Code) (Brickell et al. 2016).

Botanical precedence has been cited for preferential use of *variety* over *group* in infra-specific classification (Kays and Silva Dias 1996). However, botanical classification is dynamic and botanical variety status may change. Also, while botanical varieties of cultivated plants by definition qualify for status as horticultural groups, the reverse is not true. Consequently, variety is used for one species and group for another in some texts, and important authors differ in their use of variety and group for the same vegetables (Rubatzky and Yamaguchi 1997; Maynard and Hochmuth 2007). This inconsistent usage can easily lead to confusion. Therefore, this author proposes that *group* be used in lieu of *variety* (if not *subspecies*) as a consistent, inclusive, and uniquely horticultural term to describe subspecific categories of vegetables sharing distinct features of functional relevance. The vegetables of *Brassica oleracea*, including broccoli (Italica group), kohlrabi (Gongylodes group), Brussels sprouts (Gemmifera group), head cabbage (Capitata group), and collards (Acephala group) are well-known examples.

The cultivated variety (cultivar, cv.) is subordinate to the group classification, and is used to distinguish plants with one or more defining characteristics. Although the term *variety* is sometimes used in lieu of *cultivar*, cultivar should not be confused with the botanical variety (*varietas*, var.) as described above. To qualify for cultivar status, distinguishing characteristics must be preserved when plants are reproduced.

Although not preferred, the term *strain* is sometimes used for vegetables derived from a well-known cultivar, but with minor differences in form. *Clone* is used to describe genetically uniform plants vegetatively propagated from a single individual. The term *line* generally refers to inbred, sexually propagated individuals.

Writing Nomenclature

As with other organisms, the Latin binomial of vegetables is written in italics, with the first letter of the generic name capitalized and the specific name in lowercase letters. Current convention is to use single quotation marks to indicate cultivar status, e.g., *Phaseolus vulgaris* 'Manoa Wonder,' while use of *cv*. preceding the cultivar name is considered obsolete (Brickell et al. 2004). As a designation, the word *group* may either precede or follow the group name, and is listed in parentheses prior to the cultivar name, e.g., *Brassica oleracea* (Capitata group) 'Bravo.' The name of the person (authority) who first described the taxon may also be included in the complete name. For example, *Cucurbita moschata* Duchesne indicates that the species was named by Duchesne, while *Cucurbita moschata* (Duchesne) Poir indicates that credit for the naming is given to Duchesne in Poir (Paris 2000).

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