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Vegetable History, Nomenclature, and Classification

Introduction

All societies and ethnic groups eat vegetables because they are essential for maintaining human health. In simple terms, modern vegetable science deals with growing herbaceous plants for human consumption to meet basic nutritional needs. As the world's population grows, the demand for vegetables will continue to grow as well. Vegetable science, sometimes called olericulture, is one of the most dynamic and important fields of the agricultural sciences. The importance of vegetables has never been greater.

What is a Vegetable?

Most definitions of a vegetable are not botanically based. Vegetable definitions are rather arbitrary by nature and commonly based on usage rather than plant morphology. For example, one widely used definition of a vegetable is: a herbaceous plant or portion of a plant that is eaten whole or in part, raw or cooked, generally with an entree or in a salad but not as a dessert. Of course there are exceptions to this definition. Rhubarb, watermelon and cantaloupes are all considered vegetables but commonly used as desserts. Mushrooms are fungi and not plants but are generally considered to be vegetables, and their production is described in a later chapter.

Since "vegetable" is not a botanical term, some vegetables botanically speaking are also fruits. In a botanical sense, a fruit describes a ripened ovary containing seeds together with adjacent parts that are eaten at maturity. For example, tomato, pepper, bean and cantaloupe botanically speaking meet the definition of fruit, but because of the way they are traditionally used and produced they are considered to be vegetables. Therefore, since there are essentially two classification systems, some commodities may be classified as a vegetable based on their usage while at the same time they are botanically fruits.

Vegetables are a horticultural food crop. Other horticultural food crops include small fruits and tree fruits, which are usually grown as perennials. Vegetable crops may be either annuals or perennials. From a production standpoint, a vegetable crop may be defined as a high-value crop that is intensively managed and requires special care after harvest. Agriculturalists often segregate agronomic or "field" crops into a separate category as crops that are extensively grown and less intensively managed in comparison to vegetable and the other horticultural crops. Wheat, cotton, soybean, sugarcane and rice are all examples of agronomic crops. Many agronomic crops are grains that are planted and destructively mechanically harvested at full physiological maturity at the end of their life cycles. In contrast, many vegetable crops are harvested in an immature state, while still fragile, so great care must be taken to preserve their quality from the field to the consumer.

There are some exceptions to these general production definitions. Some agronomic crops such as tobacco are intensively managed and are valuable in a monetary sense but are considered agronomic for historical reasons. Irish potato is considered to be a vegetable by some but an agronomic crop to others depending on the region, type and scale of production. Corn and soybeans can be either agronomic or vegetable crops depending on the cultivars grown, their stage of maturity at harvest and their end use. While these definitions are not perfect, they do have value in allowing us to group different crops and types of production to understand better the more unique aspects of vegetable production, management and handling compared to other crops. So in summary, "vegetable" is a term based on the usage of herbaceous plants or portions of plants that are eaten whole or in part, raw or cooked, generally with an entree or in a salad but not as a dessert, that are intensively managed and may require special care after harvest to maintain quality.

Vegetable Production and Practices (G.E. Welbaum)

The Evolution of Vegetable Production

Over the years, world vegetable production has increased. For example, there was over a four-fold increase in world vegetable production from 1970 until 2009 (FAO, 2011). The long-term increase has largely been the result of a series of technological advances. The first were labor-saving technologies such as the moldboard plow, and power equipment such as trucks, tractors and harvesting equipment. Subsurface drainage systems were developed to improve productivity of chronically waterlogged soils. During the first half of the 20th century, low-cost commercial fertilizers were mass-produced, leading to dramatic improvements in fertility management and productivity. In the 1930s, new plant-breeding techniques led to development of more productive cultivars. One of the major genetic advancements during this period was the development of F-1 hybrid cultivars, which increased the productivity of some vegetables by 30% or more. Many view the period after World War II as the chemical era of agriculture as many synthetic pesticides, e.g. fungicides, insecticides and herbicides, became readily available. Chemicals were intended to more easily control crop pests to enable a large-scale, single-crop production system called monoculture where only a single crop is grown in a field and all other vegetation is excluded. The monoculture system and the related technologies like chemical pest control and concentrated synthetic-fertilizer usage were designed in part to reduce the amount of labor needed in agriculture so that one person could effectively manage more crop-production acreage and increase productivity.

During the 1970s and 1980s, concerns about human health issues led to interest in and the development of more sustainable and low-input approaches to vegetable production. Also in the past 50 years, conservation tillage practices have been developed to reduce soil erosion, decreasing the number of passes made over a field to decrease soil compaction. Plastic mulches were developed to modify soil temperatures, control weeds, reduce leaching and use less water to produce vegetables. Trickle-irrigation systems were developed to precisely apply water and nutrients to vegetable crops throughout the season. Raised-bed production systems improved drainage, encouraged better root development and reduced disease. During this same time frame, computer technology also impacted both production and management issues, increasing production efficiency.

Despite these advances, there seems to be declining interest in vegetable science as a discipline in the academic circles of many developed countries. Government sponsorship of research on applied aspects of vegetable science in many developed countries has declined in recent years as funding has been diverted to more basic research in plant science. There is a perception that research on vegetable-crop production is no longer a high priority in countries with developed agriculture industries because most of the production-related questions have already been answered or are being addressed by the private sector. Some believe that production has become “cookbook”, so advanced training is no longer necessary.

Most agriculturalists would agree that research has played an important role in advancing vegetable science to its current state. Innovative new research will be necessary in the future to meet the needs of a growing global population for safe, nutritious and sustainably produced vegetables. The need for primary information about vegetable production for the developing world remains great. Both now and in the future, research and education programs will be needed to address food safety and security issues.

In many developed countries, only a very small percentage of people are involved in food production. This has led to misconceptions and uncertainty about where vegetables come from, the effect production has on the environment, and whether or not vegetables are safe to eat. Consumers need to be educated about their food supply to intelligently discuss timely topics such as the risks and benefits of transgenic crops. Accurate scientific information needs to be readily available about this and other key issues. Vegetable science is truly fundamental to our very existence because it is a discipline that deals with the basic needs of the human race rather than its wants.

The following is a partial list of challenges that face commercial vegetable growers in many areas of the world; novel research approaches will be required to solve them. Understanding and controlling the causes of biological contamination on vegetable crops is a major challenge. Developing highly productive and efficient sustainable vegetable production systems is another. Improving the quality and nutritional value of commercial vegetables is an ongoing challenge. There is an opportunity to fully utilize the Global Positioning System (GPS) and its related technologies to improve vegetable-production efficiency. Decreasing the environmental footprint caused by intensive commercial vegetable production while using less water and energy will only increase in importance in the future.

In developed countries of the Americas and Europe, the commercial vegetable industry is dominated by large corporations with multiple production areas that can continuously produce a wide range of crops to supply supermarket chains throughout the year (Cook, 2001). Grocery chains prefer dealing with single suppliers for convenience, economies of size and uniformity of product. Vegetable industries in North America and Europe have evolved so that vegetables are grown in regions best suited for a particular crop for shipment, often to distant markets in population centers. The shift from local production to optimum production away from population centers has been occurring for decades (Cook, 2001). In the USA, Canada and some European countries, studies show that the average vegetable purchased in a supermarket traveled over 2,400 km (1,500) miles from the field before it was sold (Carlsson-Kanyama, 1997; Pirog and Benjamin, 2003). Shipping vegetables from distant markets is very energy intensive and the current realities of energy costs bring into the question the sustainability of growing vegetables for distant markets. Some experts are proposing a return to more locally grown produce by smaller farmers to improve vegetable quality, stimulate local economies, reduce energy usage and improve sustainability. However, the convenience and diversity of supermarket shopping appeals to many consumers, so commercial groceries are not likely to disappear anytime soon. These and other timely issues remind us that the vegetable industry is not static and needs to evolve to meet challenges over time just like other industries.

Much of this volume is devoted to describing commercial vegetable production practices. However, it is important to consider some of the key peripheral influences that affect production. Vegetable growers do not function in a vacuum and increasingly must adhere to local laws on water quality, waste handling, chemical usage and noise abatement. When discussing individual practices of vegetable production, we sometimes lose sight of these other influences. It is easy to forget that most vegetable-production operations are businesses that need to be profitable to survive. Production practices must make business sense in order to be adopted. We will not consider the financial aspects of vegetable production in detail because they are beyond the scope of this book, but the reader should remember that profitability plays a major role in the production practices that are selected by farmers.

Vegetable Diversity

The diversity of vegetables consumed by humans varies widely with both geography and culture. It is difficult to estimate the diversity of vegetables grown around the world, but the number of unique vegetables is likely in the thousands. Vegetables are increasingly traded internationally. It is common to buy fresh vegetables in northern European countries that were grown in southern Europe or Israel. In North America it is common to buy vegetables grown in Holland, Guatemala, Chile or New Zealand. Vegetable growers in the USA ship fresh broccoli and melons to Southeast Asia. Improved transportation systems make the long-distance movement of vegetables possible across regions and among countries. Efficient transportation enables the long-distance transport of vegetables for sale in areas where they are out of season or cannot be grown due to unfavorable climate. Improved postharvest handling of vegetables allows maintaining marketable quality for longer periods through improved genetics and postharvest handling conditions. For example, slow-ripening durable cultivars of tomato have been developed to better withstand long-distance transport. The diversity of vegetables available to consumers has also been increased through new introductions and cultivar development. Cultivars of colored lettuce with diverse leaf shapes add color and appeal to salads, an array of colored bell peppers are visually attractive, purple asparagus, yellow-fleshed watermelon, green cauliflower and purple broccoli are other examples of diverse types that appeal to consumers. The production of new vegetables often occurs following their introduction.

Domestication and History of Vegetables

It is interesting to briefly discuss the history to understand the origins of the vegetables we eat today. Scientific evidence shows that the vegetables of today did not suddenly appear on earth, but have evolved over a very long period of time thanks to natural selection, human selection, and more recently plant breeding and other forms of genetic improvement. Ethnobotany is the scientific study of the relationships that exist between people and plants. From the studies of anthropologists and enthobotanists, we know that ancient humans were not farmers.

Early humans existed on earth over 2 million years ago and gathered all kinds of plants from the wild to supplement food obtained from hunting and fishing. The ample food supply allowed humans to establish residence rather than pursue a nomadic existence. Having a stable food supply and a place to live allowed people to think about things other than their personal survival, such as growing crops rather than gathering them. About this point, humans began the long process of food-crop domestication. Domestication describes a selection process conducted by humans to produce plants that have more desirable traits. Several conditions are believed to have been necessary, or at the very least helpful, in leading humans to domesticate plants:

1. Fire was used to clear land of vegetation in some areas. The "slash and burn" method is still used in some areas to clear land.
2. A temperate or subtropical climate with distinct wet and dry seasons helped facilitate seed-crop production. The Middle East was especially suited to seed-crop production because the dry summer climate was conducive to the evolution of large-seeded annual plants, and the variety of elevations in the region led to a great variety of species (Balfour-Paul, 1996).
3. Location was an important consideration. Since river valleys were subject to periodic flooding, grasslands were difficult to till with primitive tools and rainforests were difficult to clear, early humans most likely used open woodlands to attempt cultivation.
4. Areas with a diversity of plants and abundant animal supplies for food were prime targets for crop domestication.

Conscious cultivation and trait selection of plants may have occurred in what is today Syria as early as c. 11,050 BC, but this appears to have been a localized phenomenon rather than a definitive step towards domestication (Hillman *et al.*, 2001). The earliest human attempts at plant domestication likely occurred in southwestern Asia and the Middle East about 10,000 years ago (Zohary and Hopf, 1988). By 10,000 BC, the bottle gourd, *Lagenaria siceraria*, appears to have been domesticated as a container and not a vegetable before the invention of ceramic technology. Interestingly, the domesticated bottle gourd reached the Americas from Asia as early as 8000 BC, most likely due to the migration of peoples from Asia who had domesticated the crop 2,000 years earlier (Erickson *et al.*, 2005). By comparison, cereal crops were likely first domesticated around 9000 BC in the Fertile Crescent between the Tigris and Euphrates rivers region in the Middle East (Balfour-Paul, 1996). Starchy seeds were gathered as food during the dry season. The domestication process began when starchy seeds that were dropped or spilled near dwellings during the dry season germinated and grew rapidly due to the lack of competition during the rainy season. These adventitious plants benefited from the increased fertility near dwellings and protection from animal predation. Vegetative plants like sweetpotato were likely collected in the tropics, semi-tropical regions of the Americas, Southeast Asia and Africa. When digging wild roots and tubers with sharp sticks, some of the roots undoubtedly remained in the ground to regrow. Some of the roots and tubers may have dropped or been discarded near encampments, only to regrow in areas with adequate rainfall.

Harvesting unintentional plantings evolved into the practices of intentionally planting seeds or vegetative plant parts into soil. The domestication of vegetables resulted from years of human selection of plants with more desirable traits. The first domesticated vegetable crops were generally annuals with large seeds, or fruits including legumes such as peas, and not herbaceous vegetable crops (Zohary and Hopf, 1988).

As domestication took place, humans began to shift from a hunter-gatherer society to a settled agricultural society. The establishment of agricultural societies led to the first city states and eventually the rise of civilization itself. So crop domestication was a key development in human evolution whose importance should not be discounted. Continued domestication was gradual, a process of trial and error that occurred intermittently. Outside the Middle East/West Asia, very different species were domesticated. In the Americas cultivation of squash, corn, potato and beans was adapted. In East Asia millet, rice and soy were the most important early crops (Zohary and Hopf, 1988).

Genetic Change and Germplasm Preservation

Domestication renders plants dependent on humans for their continued existence. Many domesticated plants show little or no resemblance to their natural ancestors (Smartt and Simmonds, 1995). The divergence between wild and cultivated plants occurred because of different mechanisms that ultimately resulted in genetic changes. For example, corn ears are now dozens of times the size of those of wild teosinte, which is believed to be the closest non-domesticated relative of corn. Modern cantaloupe cultivars have much larger fruit than their wild relatives and have been selected for crack resistance to the point that the seeds inside often die before being released from the fruit, so the plants can no longer survive in the wild (Welbaum, 1993). Seed stalks have difficulty breaking through the heads of crisphead lettuce unless slashed with a knife to allow flowering to occur.

The diversion between crops and native plants occurred because large populations of wild plants that were first selected for domestication were genetically very diverse. Saving seeds from wild plants selected for desirable traits obtained through natural hybridization and genetic recombination resulted in crops possessing traits that were desirable to humans but different from the average plant in a wild population. Another cause for the divergence between wild and cultivated plants was genetic mutation. Natural gene mutations occurred infrequently and most of the new characteristics that resulted from mutation were deleterious, leading to their elimination. Occasionally, mutations produced desirable qualities, like increased size, for example, that benefited humans. Through natural mutations, hybridizations and chromosome duplications, plants slowly changed over thousands of years. Natural genetic changes, combined with breeding crop plants in more recent times, gradually changed some plants so they no longer resembled their wild progenitors. Plant breeding is the art and science of changing the genetics of plants for the benefit of mankind using many different techniques. These range from simply selecting plants with desirable characteristics for propagation to more complex techniques (Poehlman and Sleeper, 1995). It is sometimes forgotten that plant breeding has been practiced for thousands of years, since near the beginning of human civilization.

The domestication of food crops by humans has caused our food supply to become increasingly dependent on a limited number of cultivars for many vegetables. Preserving genetic resources has become a higher priority for many groups in recent years. International collaboration on germplasm preservation issues has increased as well. Many countries maintain germplasm collections, such as the United States National Center for Genetic Resources Preservation (NCGRP) in Fort Collins, Colorado, the Kew Royal Botanical Garden's Millennium Seed Bank located at Wakehurst Place in Sussex, England, and the N.I. Vavilov All-Russian Scientific Research Institute of Plant Industry in St. Petersburg, Russia, where the world's first seed bank and one of the world's largest collections of plant genetic material is maintained. The Svalbard Global Seed Vault is a secure international seed bank located on the Norwegian island of Spitsbergen that preserves a wide variety of plant seeds, including vegetables, in an underground cavern. The seeds are duplicate samples, or "spare" copies, of seeds held in gene banks worldwide. The seed vault and other germplasm collections provide insurance against the loss of seeds in other gene banks, as well as a refuge for seeds in the case of large-scale regional or global crises. These germplasm collections are also available for genetic improvement of crop plants and provide sources of novel genes that are currently not needed but may be useful in the future.

The news media often describes modern transgenic crops that have been engineered using various recombinant DNA technologies as "genetically modified". Unfortunately, this terminology leads us to believe that vegetables and other crops were not changed genetically until the 1980s when recombinant DNA technologies for crop improvement were created. The above discussion illustrates that genetic modification of plants is a natural continuous process caused by mutation, hybridization, chromosome duplication, human selection, and plant breeding that has produced the vegetable crops grown throughout the world today. We will discuss the genetic improvement of vegetables in greater detail in a later section.

Centers of Origin

The Russian botanist Nikolai Vavilov described Centers of Origin as locations where the original center for the domestication of certain crop plants likely occurred (Ladizinsky, 1998). Vavilov believed that plants were not domesticated somewhere in the world at random, but there were specific regions where the domestication started (Fig. 1.1). It is believed that the center of origin is also the center of genetic diversity.

Vavilov centers are regions where a high diversity of crop-related plants can be found. These plants, called crop wild relatives, represent the progenitors of domesticated crop plants and are studied by ethnobotanists and geneticists for use in the genetic improvement of modern cultivars or for preservation in germplasm collections. Almost all the vegetables grown today were domesticated from Centers of Crop Origin (Table 1.1).

Domesticated plant species often differ from their wild relatives in predictable ways. These differences are often called the "domestication syndrome" and include the following changes that were necessary for the domestication of wild plants to be successful:

1. Gigantism: the size of plants, reproductive organs and seeds increased through natural genetic selection. This also includes changes in biomass allocation (more in fruits, roots or stems, depending on human selection). Gigantism is the reason why wild plants and berries are smaller than their domesticated relatives.
2. Seeds: during domestication, seeds generally became larger, decreased in number, lost the ability to shatter (fall off the plant) prematurely, and lost dormancy. Most modern vegetable seeds lack dormancy compared to wild plants.
3. Maturity: domesticated plants mature earlier and have more concentrated seed production.
4. Defenses: domesticated plants have reduced physical (e.g. thorns) and chemical defenses.

Many vegetables familiar to us today were unknown to Europeans before Columbus discovered the New World. Indigenous peoples of the Western Hemisphere domesticated many of our most important world vegetables long before the Europeans were aware of their existence. When vegetables were taken from their original habitat in the New World and introduced to Europe, some were initially very successful because there were fewer diseases and insects and lack of competition. An example of this would be the "Irish" potato, whose center of origin is South America. The Irish potato grew well initially in Ireland after its introduction because the climate was favorable and there were no diseases. The potato became a staple crop that the Irish people came to be overly reliant upon. Eventually diseases caused potato crop failures in Ireland, resulting in famine and emigration that altered the history of the entire country.

Vegetable Classification Systems

A systematic method for grouping different plants is important for identifying and cataloguing the large volume of information about the many diverse plants that exist on earth. A proper and efficient classification system can result in more efficient use of information. Of the hundreds of thousands of

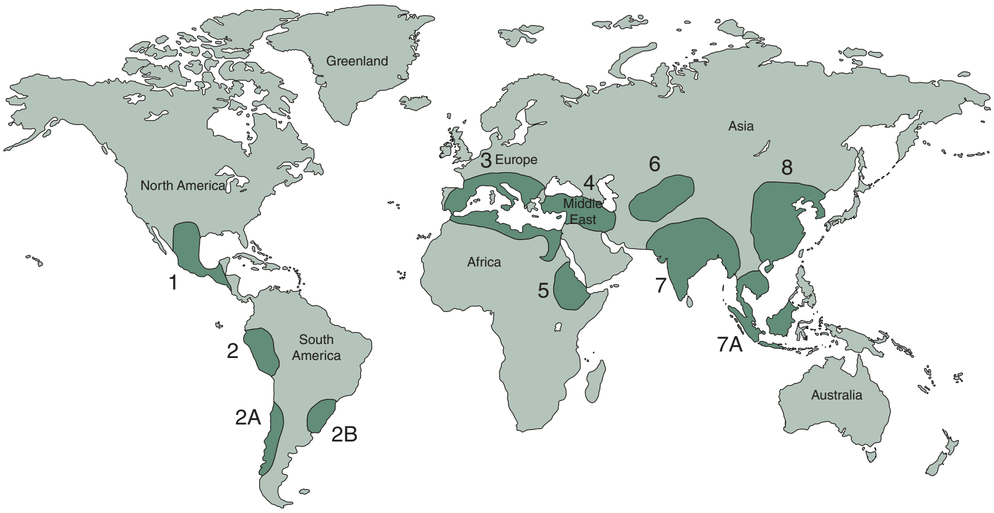

Fig. 1.1. Primary centers of origin of cultivated plants (Ladizinsky, 1998). Center descriptions are in Table 1.1.

Table 1.1. The following crops have been identified as Centers of Crop Origin in both the New and Old World as shown in Fig. 1.1 (Schery, 1954). The numbers for each center refer to regions in Fig. 1.1.

New World

1. South Mexican and Central American Center – southern sections of south Mexico and Central America.
Corn (*Zea mays*)
Common bean (*Phaseolus vulgaris*)
Lima bean (*Phaseolus lunatus*)
Malabar gourd (*Cucurbita ficifolia*)
Winter pumpkin (*Cucurbita moschata*)
Chayote (*Sechium edule*)
Sweetpotato (*Ipomoea batatas*)
Arrowroot (*Maranta arundinacea*)
Pepper (*Capsicum annuum*)
2. Northern South American Center – Peru, Ecuador, Bolivia
Andean potato (*Solanum andigenum*)
Potato, common (*Solanum tuberosum*) (24 chromosomes)
Starchy corn (*Zea mays*)
Lima bean (*Phaseolus lunatus*) secondary center
Common bean (*Phaseolus vulgaris*) secondary center
Edible canna (*Canna edulis*)
Pepino (*Solanum muricatum*)
Tomato (*Solanum lycopersicum*)
Ground cherry (*Physalis peruviana*)
Pumpkin (*Cucurbita maxima*)
Pepper (*Capsicum annuum*)
2A. Chiloe Center – islands near coast of Chile
Potato, common (*Solanum tuberosum*) (48 chromosomes)
2B. Brazilian-Paraguayan Center
Cassava (*Manihot esculenta*)
3. Mediterranean Center – includes the borders of the Mediterranean Sea
Pea (*Pisum sativum*)
Garden beet (*Beta vulgaris*)
Cabbage (*Brassica oleracea*)
Turnip (*Brassica rapa*)
Lettuce (*Lactuca sativa*)
Celery (*Apium graveolens*)
Chicory (*Cichorium intybus*)
Asparagus (*Asparagus officinalis*)
Parsnip (*Pastinaca sativa*)
Rhubarb (*Rheum officinale*)
4. Near-Eastern Center – Asia Minor – Transcaucasia, Iran and Turkey
Lentil (*Lens esculenta*)
Lupine (*Lupinus albus*)
5. Ethiopian (Abyssinian) Center – Ethiopia and Somali Republic
Cowpea (*Vigna unguiculata*)
Garden cress (*Lepidium sativum*)
Okra (*Hibiscus esculentus*)
6. Central Asiatic Center – northwest India (Punjab and Kashmir), Afghanistan
Pea (*Pisum sativum*)
Horse bean (*Vicia faba*)
Mung bean (*Phaseolus radiata*)
Mustard (*Brassica juncea*)
Onion (*Allium cepa*)
Garlic (*Allium sativum*)

Continued

Table 1.1. Continued.

Spinach (*Spinacia oleracea*)
Carrot (*Daucus carota*)
7. Northeast India and Myanmar (Burma) Center
Mung bean (*Phaseolus aureus*)
Cowpea (*Vigna sinensis*)
Eggplant (*Solanum melongena*)
Taro (*Colocasia esculenta*)
Cucumber (*Cucumis sativus*)
Yam (*Dioscorea alata*)
7A. Indo-Malayan Center (Indo-China and Malay Archipelago)
Banana (*Musa paradisiaca*) (starchy fruit used as vegetable)
Breadfruit (*Artocarpus communis*)
8. Chinese Center – mountains of central and western China and adjacent lowlands.
Soybean (*Glycine max*)
Chinese yam (*Dioscorea batatas*)
Radish (*Raphanus sativus*)
Chinese cabbage (*Brassica campestris*) (Chinensis and Pekinensis groups)
Onion (*Allium chinense* and *A. fistulosum*)
Cucumber (*Cucumis satvus*)

plants known in the world, only several hundred are used as vegetables. However, in order to manage information about plants, some system of classification, preferably having universal applicability, is beneficial. Many different classification systems have been developed, but the value of any system depends on its usefulness. To be useful, a classification system needs to be simple to use, accessible to all, and stable over time. The following section introduces different classification systems that are useful in the study of vegetable crops.

Fresh versus processed

One of the most common classifications of vegetables is whether they are consumed fresh or processed. Since vegetables are perishable, they are often canned, frozen or dried for long-term preservation. Of course, vegetables can also be eaten fresh or lightly processed in a prewashed ready-to-eat form that is more convenient for consumers. The lightly or minimally processed value-added category has resonated with consumers in many countries because there is a demand for the flavor and nutritional benefits of fresh vegetables without the labor and extra time needed for preparing raw vegetables for eating.

Fresh
A – raw: no washing or packaging
B – washed and wrapped, but not ready to eat
C – lightly (or minimally) processed, cut, washed and ready to eat with no further preparation

Processed
A – canned
B – frozen
C – dried

Thermo-classification of vegetables

Classification by climate was probably one of the earliest attempts to group plants and it is still widely used today. Through long-term observation, plants were grouped by optimum growing temperatures as either warm- or cool-season plants. Cool-season vegetables show a preference during most of their development for mean growing temperatures between 10°C and 18°C (50–64°F). Some have frost (surface ice formation) and freeze tolerance and for most, the edible tissues are leaves, stems or roots. Frost is defined as ice crystals that form on the surface of vegetables, while freezing is ice formation inside plant tissues. Familiar examples of cool-season vegetables are cabbage, lettuce, spinach, potato, and carrot.

In contrast, warm-season crops exhibit a preference for mean temperatures from 18°C to 30°C (64–86°F) during most of their growth and development. Warm-season vegetables are often of tropical origin and are perennial plants, but are grown in temperate regions as annuals. Warm-season crops are intolerant of frost and many are chilling sensitive. Chilling injury is primarily a disorder of crops of tropical and subtropical origin and is not the same as freezing injury. Chilling injury generally occurs when vegetables are exposed to 10–13°C (50–55°F). Chilling-sensitive crops have a short storage life at low temperatures and deteriorate more rapidly when returned to warm temperatures because of damage to cell membranes. Botanically, the edible tissues of many warm-season vegetables are reproductive organs. Examples include tomato, melons, and beans. Temperature classifications based on growing temperature or seasonal periods provide us with useful generalities, but upon closer examination there are overlaps and exceptions. Thermo-classification is useful to classify plants grown in temperature zones because in the tropics, the distinction between warm- and cool-season vegetables is less clear (Rubatzky and Yamaguchi, 1997).

Cool-season crops
Group A: prefer average monthly temperatures of 15.6–18.3°C (60–65°F). Intolerant of 21.1–23.9°C (70–75°F) and slightly tolerant of freezing; e.g. spinach, cabbage, parsnip, broccoli, radish, beet, turnip, rutabaga, cauliflower
Group B: prefer 15.6–18.3°C (60–65°F). Intolerant of 21.1–23.9°C (70–75°F). Damaged near maturity by freezing; e.g. lettuce, celery, artichoke, endive, carrot, chard
Group C: adapted to 12.8–23.9°C (55–75°F). Tolerant of frost; e.g. asparagus (mature plants), garlic, kale, Brussels sprouts

Warm-season crops
Group D: adapted to 18.3–29.4°C (65–85°F). Intolerant of frost. Chilling sensitive and damaged by exposure to or storage at temperatures below 13°C (55°F); e.g. sweet corn, pepper, snap bean, squash, pumpkin, lima bean, cucumber, tomato, muskmelon
Group E: long-season crops; prefer temperatures above 21.1°C (70°F). Chilling sensitive and damaged by exposure to or storage at temperatures below 13°C (55°F); e.g. watermelon, sweetpotato, eggplant, okra

The following are some other examples of useful classification systems that are frequently used to group vegetables. Additional classification systems also exist.

Classification of vegetables based on use, botany or a combination of both

Potherbs or greens
Spinach, kale, New Zealand spinach, mustard, chard, collards, dandelion

Salad crops
Celery, chicory, lettuce, watercress, endive

Cole crops (all are members of *Brassica oleracea* except Chinese cabbage)
Cabbage, Brussels sprouts, cauliflower, kohlrabi, sprouting broccoli, Chinese cabbage

Root crops (refers to crops which have a fleshy taproot)
Beet, turnip, carrot, rutabaga, parsnip, radish, salsify, celeriac

Bulb crops (*Allium* spp.).
Onion, garlic, leek, shallot, Welsh onion

Pulses or legumes
Peas, beans (including dry-seeded or agronomic forms)

Cucurbits (all members of the Cucurbitaceae)
Cucumber, pumpkin, muskmelon, squash, watermelon, several oriental crops

Solanaceous fruits (members of the Solanaceae)
Tomato, eggplant, pepper, husk tomato

Classification by edible part

Root
Enlarged taproot; e.g. beet, rutabaga, carrot, turnip, radish, parsnip, salsify, celeriac
Enlarged lateral root; e.g. sweetpotato, cassava

Stem
Above ground – not starchy; e.g. asparagus and kohlrabi
Below ground – starchy; e.g. white or Irish potato, Jerusalem artichoke, yam, taro, Andean tubers (oca, ullucu, anu)

Leaf
Onion group – leaf bases eaten (except chives); e.g. onion, garlic, leek, chive, shallot
Broad-leaved plants
Salad use; e.g. lettuce, chicory, celery (petiole only), endive, cabbage
Cooked (may include tender stems in some); e.g. spinach, kale, chicory, chard, vegetable amaranth, Chinese cabbage, mustard, dandelion, cardoon (petiole only), rhubarb (petiole only)

Immature flowers
Cauliflower, broccoli raab, broccoli, globe artichoke

Fruit
Immature; e.g. pea, chayote, okra, snap bean, summer squash, sweet corn, lima bean, cucumber, eggplant, broad bean
Mature; e.g. gourd family (cucurbits: pumpkin, winter squash, muskmelon, watermelon), tomato family (tomato, pepper, husk tomato)

Classification of vegetables according to salt tolerance

Salt concentration upper limits based on saturation soil extracts.

High salt tolerance: 7,700 ppm
Garden beets, kale, asparagus, spinach

Medium salt tolerance: 6,400 ppm
Tomato, broccoli, cabbage, peppers, cauliflower, lettuce, sweet corn, white potato, carrot, onion, peas, squash, cucumber, cantaloupe

Low salt tolerance: 2,600 ppm
Radish, green bean

All other vegetables: 1,900 ppm

Classification of vegetables according to tolerance to soil acidity

Slightly tolerant: pH 6.8–6.0
Asparagus, celery, muskmelon, beet, spinach, New Zealand spinach, broccoli, Chinese cabbage, okra, cabbage, leek, onion, cauliflower, lettuce, spinach

Moderately tolerant: pH 6.8–5.5
Bean, horseradish, pumpkin, Brussels sprouts, kohlrabi, radish, carrot, parsley, squash, cucumber, pea, tomato, eggplant, pepper, turnip, garlic

Very tolerant: pH 6.8–5.0
Chicory, rhubarb, endive, sweetpotato, potato, watermelon

Classification by root depth into soil

Shallow: 80 cm (36 in)
Cabbage, lettuce, onion, potato, spinach, sweet corn

Medium: 80–160 cm (36–72 in)
Beans, beets, carrot, cucumber, eggplant, summer squash, peas

Deep: 160 cm (as deep as 72 in)
Globe artichoke, asparagus, sweetpotato, tomato

Botanical classification system

All of the classification systems mentioned thus far overlap and although they are generally useful, they are inadequate for precise identification. The botanical classification system is the most precise, universal, and useful. Botanical classification is largely based on the variability among plants with regard to flower type, morphology, and sexual compatibility. All plants are considered as one community.

The famous botanist L.H. Bailey lists four subcommunities of plants. These are: (i) algae and fungi; (ii) mosses and liverworts; (iii) ferns; and (iv) seed plants. Vegetables are primarily seed-bearing plants, but by general agreement mushrooms, a fungus, are included (Bailey, 1949). The subgroupings most useful to the discussion of vegetables are family, genus, species, and cultivars (Table 1.2). The scientific names in this system are in Latin, which adds stability since this language will not change. This classification system, also known as the Latin binomial, was published as *Species Plantarum* in 1753 by Linnaeus and tends to be the most exact and accepted internationally.

Although the botanical classification system has stood the test of time relatively well, modern genetic tools have shown certain classifications based on plant morphology to be incorrect. For example, the Latin binomial for tomato has been changed from the long-standing *Lycopersicon esculentum* to *Solanum lycopersicon* based on molecular phylogenetic analyses (Bohs, 2005). More changes in the botanical system of vegetables can be anticipated in the years ahead as additional molecular phylogenetic studies are conducted. In some cases, molecular analyses show that genetic differences are not as significant as the phenotype or appearance of a vegetable may suggest. An example of this occurs with the classification of seemingly different vegetables into separate botanic varieties (also called subspecies). This confusion in nomenclature is due to the fact that some molecular genetic studies have shown that major morphological differences may be caused by single or few genes and therefore do not warrant classification into separate botanical varieties or as subspecies. An example of this would be cauliflower (family: Brassicaceae; genus: *Brassica*; species: *oleracea*; botanical variety: botrytis). Molecular genetic studies have shown that a single gene controls the development of undifferentiated flower primordial (curd) and if

Table 1.2. Botanical classification of vegetables. This table includes only monocots and dicots. Some vegetables like mushrooms are fungi and do not fit into either category (Rubatzky and Yamaguchi, 1997; GRIN, 2010; ePIC, 2011; USDA, 2011).

I. Monocotyledoneae	
Amaryllidaceae, Subfamily Allioideae (formerly Alliaceae) – Amaryllis Family	
Allium ampeloprasum var. ampeloprasum	Elephant garlic
Allium ampeloprasum var. kurrat	Kurrat
Allium ampeloprasum var. porrum	Leek
Allium tricoccum	Wild leek, ramp
Allium cepa (Aggregatum group)	Shallot
Allium cepa (Cepa group)	Common onion
Allium cepa (Proliferum group)	Egyptian onion
Allium chinense	Chinese onion, Chinese scallion, Oriental onion
Allium fistulosum	Welsh onion, Japanese bunching onion
Allium sativum	Garlic
Allium schoenoprasum	Chive
Allium tuberosum	Chinese chives
Dioscoreaceae – Yam Family	
Dioscorea alata	Water yam, winged yam, purple yam
Dioscorea bulbifera	Air potato, varahi, kaachil
Dioscorea cayenensis	Yellow yam
Dioscorea esculenta	Lesser yam
Dioscorea opposita	Chinese yam
Dioscorea rotundata	White yam
Dioscorea trifida	Cush-cush yam, Indian yam, napi
Poaceae (old name Gramineae) – Grass Family	
Zea mays var. indentata	Dent corn, field corn
Zea mays var. indurata	Flint corn, ornamental corn
Zea mays var. everta	Popcorn
Zea mays var. saccharata	Sweet corn
Asparagaceae (formerly Liliaceae)	
Asparagus officinalis	Asparagus
II. Dicotyledoneae	
Most vegetables fall into this category.	
Amaranthaceae (subfamily Chenopodiaceae, formerly family) – Goosefoot Family	
Atriplex hortensis	Orach
Beta vulgaris var. cicla	Chard
Beta vulgaris var. crassa	Beet
Spinacia oleracea	Spinach
Asteraceae (Compositae outdated name) – Sunflower Family	
Artemisia dracunculus	Tarragon
Cichorium endivia	Endive, escarole
Cichorium intybus	Chicory, radicchio
Cynara cardunculus	Cardoon
Cynara scolymus	Globe artichoke
Helianthus tuberosus	Jerusalem artichoke
Lactuca sativa	Lettuce
Taraxacum officinalis	Dandelion
Tragopogon porrifolius	Salsify, oyster plant
Convolvulaceae – Morning-glory Family	
Ipomoea aquatica	Water spinach
Ipomoea batatas	Sweetpotato

Continued

Table 1.2. Continued.

Brassicaceae (Cruciferae outdated name) – Mustard Family	
Armoracia rusticana	Horseradish
Sinapis alba	White mustard
Brassica juncea	Leaf mustard
Brassica napus (Napobrassica group)	Rutabaga
Brassica napus (Pabularia group)	Siberian kale
Brassica nigra	Black mustard
Brassica oleracea (Acephala group)	Kale, collard
Brassica oleracea (Alboglabra group)	Chinese kale
Brassica oleracea (Botrytis group)	Cauliflower
Brassica oleracea (Capitata group)	Cabbage
Brassica oleracea (Gemmifera group)	Brussels sprouts
Brassica oleracea (Gongylodes group)	Kohlrabi
Brassica oleracea (Italica group)	Broccoli
Brassica oleracea (Costata group)	Tronchuda cabbage
Brassica rapa (Chinensis group)	Chinese cabbage (nonheading), pak-choi
Brassica rapa (Pekinensis group)	Chinese cabbage (heading), pe-tsai
Brassica rapa (Perviridis group)	Spinach mustard
Brassica rapa (Rapifera group)	Turnip
Brassica rapa (Ruvo group)	Broccoli raab, rapini
Lepidium sativum	Garden cress
Crambe maritime	Sea kale
Nasturtium officinale	Watercress
Raphanus sativus	Radish
Cucurbitaceae – Gourd Family	
Citrullus lanatus	Watermelon
Cucumis melo (Inodorus group)	Honeydew melon, casaba, crenshaw, persian
Cucumis melo (Cantaloupensis group)	Muskmelon, cantaloupe
Cucumis sativus	Cucumber
Cucurbita maxima	Winter squash, pumpkin, banana squash, buttercup squash, hubbard squash
Cucurbita argyrosperma	Green cushaw, Japanese pie pumpkin, silver-seed gourd
Cucurbita moschata	Butternut squash, calabaza, cheese pumpkin, golden cushaw
Cucurbica pepo	Pumpkin, acorn squash, summer squash, marrow
Lagenaria siceraria	Bottle gourd, calabash gourd
Luffa aegyptiaca	Smooth sponge gourd
Luffa acutangula	Ridged sponge gourd
Momordica charantia	Bitter melon
Sechium edule	Chayote
Euphorbiaceae – Spurge Family	
Manihot esculenta	Cassava, yuca
Fabaceae (Leguminosae old name) – Pea or Bean Family	
Cicer arietinum	Chickpea, garbanzo bean
Glycine max	Soybean
Lens culinaris	Lentil
Phaseolus coccineus	Scarlet runner bean
Phaseolus lunatus	Lima bean, sieva bean (butter bean)
Phaseolus vulgaris	Common bean (green, dry), snap bean, kidney bean
Pisum sativum	Garden pea, field pea, edible-pod pea
Psophocarpus tetragonolobus	Winged bean
Vicia faba	Fava bean (broad bean)
Vigna mungo	Urad, urd, black gram
Vigna radiata	Mung bean
Vigna unguiculata	Black-eyed pea, cowpea, asparagus bean, yard-long bean

Continued

Table 1.2. Continued.

Malvaceae – Mallow or Cotton Family	
Abelmoschus esculentus	Okra, gumbo
Polygonaceae – Buckwheat Family	
Rheum rhabarbarum	Rhubarb
Rumex acetosa	Sorrel
Rumex patientia	Dock, patience or monk's rhubarb
Solanaceae – Potato or Nightshade Family	
Capsicum annuum	Pepper (bell, cayenne chili)
Capsicum frutescens	Tabasco pepper
Solanum lycopersicon	Tomato, cherry tomato
Solanum pimpinellifolium	Currant tomato
Physalis pruinosa	Strawberry ground cherry
Physalis philadelphica	Tomatillo
Physalis peruviana	Cape gooseberry
Solanum melongena	Eggplant
Solanum tuberosum	Irish potato
Tetragoniaceae – Carpetweed Family	
Tetragonia tetragoniodes	New Zealand spinach
Apiaceae (formerly Umbelliferae) – Parsley Family	
Anthriscus cerefolium	Chervil
Apium graveolens (Dulce group)	Celery
Apium graveolens (Rapaceum group)	Celeriac
Daucus carota	Carrot
Foeniculum vulgare	Fennel
Pastinaca sativa	Parsnip
Petroselinum crispum	Parsley, turnip-rooted parsley
Valerianaceae – Valerian Family	
Valerianella locusta	Corn salad, mâche

The complete Latin binomial name includes a third element, the naming authority, which is not shown above. The name of the individual who first described the species is usually included after the Latin binomial. For example, the "L" that follows some vegetable species' names is an abbreviation for C. Linnaeus, who is considered to be the father of the Latin binomial classification system and was first to name a number of the vegetable species. For brevity, attached authorships for species mentioned in this publication are omitted.

this gene is expressed in broccoli or cabbage, the plants also produce a curd like cauliflower (Franco-Zorrilla *et al.*, 1999). Because of this and other genetic comparison studies, there has been a growing consensus among plant biologists that it is invalid to subdivide *Brassica* species into distinct botanical varieties. However, cauliflower is obviously different from cabbage and the other crops in *Brassica oleracea*. To make light of these horticultural differences, other references classify cauliflower as *Brassica oleracea* Group Botrytis rather than the botanical variety botrytis, which is more common in older literature (Griffiths, 1994). Therefore, the term Group (gp.) is used to show horticultural differences within a species that were previously classified into separate botanical varieties or subspecies.

Taking the cauliflower example a step further, 'Snowball' is a particular cultivar of cauliflower, Y is a particular strain of 'Snowball', and different production fields of 'Snowball' could be designated as individual lots. A Snowball type would refer to cultivars with the same basic characteristics as 'Snowball' (e.g. an early maturing cultivar that does not require vernalization to develop a curd) and would include all the various strains of 'Snowball'. For example, a cauliflower grower may ask a seed salesman if a cultivar is a "Snowball type" even though it may have a different cultivar name.

Classification of cantaloupe as an example

The following illustration shows the main divisions in plant classification and demonstrates how cantaloupe would be classified from general information to more specific:

- Vegetable Community – Plants
- Subcommunity – Spermatophyta (seed plants)
- Division – Angiospermae (angiosperms)
- Class – Dicotyledoneae (dicotyledons)
- Family – Cucurbitaceae
- Genus – *Cucumis*
- Species – *melo* L.
- Botanical Variety, Subspecies, or Group – Cantaloupensis (in this example, note this is not italicized and is capitalized.)
- Cultivated Variety (Cultivar) – ‘Top Mark’
- Horticultural Strain – Seed company selection
- Stock or Lot Number – 1476

Generally speaking, genus and species names are italicized as a standard convention, especially when used together. Please note the difference between cultivar and variety. Notice in the example below that Top Mark is a cultivar and not a variety. Also, single quotes are used to signify a cultivar, e.g. ‘Top Mark’.

Classification terminology

Family: an assemblage of genera that closely and uniformly resemble one another in general appearance and technical characters.

Genus: a more or less closely related and definable collection of plants that may include one or more species. The species in the genus are usually structurally or phylogenetically related, but do not routinely intercross.

Species: a group of similar organisms capable of interbreeding and are more or less distinctly different in morphological or other characteristics, usually reproductive parts, from other species in the genus.

Botanical Variety: a subdivision of a species consisting of a population with morphological characteristics distinct from other species’ forms and is given a Latin name according to the rules of the International Code of Botanical Nomenclature. Variety was and continues to be used erroneously when the correct term is intended to be cultivar.

Group: a category of cultivated plants at the subspecies level that have the same Latin binomial, but have one or more characteristics sufficiently unique to merit a name that distinguishes them from another category. The term is used for horticultural convenience and has no botanical significance. Thus, botanical variety, subspecies, and group are similar and therefore often used interchangeably.

Cultivar: contraction for “cultivated variety”; a plant that is clearly distinguished by identical physical characteristics and maintains these characteristics through proper propagation means.

Cultigen: a plant or group of plants known only in cultivation without a determined nativity, presumably having originated in its presently known form under domestication (Rubatzky and Yamaguchi, 1997). A plant whose origin or selection is due primarily to intentional human activity is called a cultigen. (A cultivated crop species that has evolved from wild populations due to selective pressures from traditional farmers is called a landrace.)

Clone: a population derived from a single individual and maintained by vegetative propagation. Individual members of a cloned population are genetically identical and can be maintained essentially uniformly with relatively little selection.

Landraces: plants that are ideally suited to a particular region or environment as the result of natural forces.

Line: a uniform sexually reproduced population, usually self-pollinated, that is seed propagated and maintained to the desired standard of uniformity by selection.

Strain: an improved selection of a cultivar that possesses similar characteristics, but differs in some minor attribute or quality.

Lot: a particular batch of seeds that were produced and processed together.

Type: a series of cultivars of a crop that have similar characteristics without specific reference to genetic or morphological characteristics.

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