5

The Americas

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Introduction

Figure 5.1 Political map of the Americas (courtesy of United States of America Central Intelligence Agency).

Europeans called America the "New World" because it was unknown to them prior to the sixteenth century. Today the term is still used, especially when referring to the origin of plants. America is named after Italian explorer Amerigo Vespucci, who visited South America from 1497 to 1502. He speculated that South America was not the East Indies, but an entirely new continent unknown to Europe. Christopher Columbus used the term "Indian" to describe Native Americans because he thought he had reached the Indian Ocean. The islands where Columbus first landed are still called the West Indies. Most likely the first humans came to America from Asia during the last Ice Age, either walking across the Bering Strait land bridge or taking boats across the shallow waters. They eventually migrated south and east, forming tribal groups and giant empires over the course of several millennia.

Ranging from the Arctic Circle across the equator to the southernmost tip of Argentina, the Americas have a wide range of topography, climates, and ecosystems (Figure 5.1). Likewise, there are a variety of languages, religions, and cultures. In general, native tribes lived sustainable, subsistence lifestyles where ethnobotany was critical to survival. It was an oral tradition, passed down through the generations. This chapter will focus on Native American ethnobotany, with a smaller amount of information on the European Diaspora that dominates the Americas today. The Americas can be separated into the following regions: North, Central, and South America, and the Caribbean islands.

North America

Before the arrival of Europeans during the sixteenth to nineteenth centuries, North America was home to an estimated 18 million indigenous people from hundreds of different tribes. North America can be divided into separate cultural areas with different lifestyles. Tribes in areas where resources were scarce, such as the Great Basin, were nomadic, but most other tribes lived in settled villages. Some were farmers (e.g., Algonquian and Muskogean language tribes) but a great number were hunter-gatherers, collecting wild plants for food and medicine. Great Plains inhabitants were traditionally hunters and farmers in settled villages. But after the arrival of the Europeans disrupted their way of life, they became nomadic. The Navajo and Apache of the Southwest were somewhat nomadic, hunting, gathering, and raiding villages for crops.

Many farming tribes were known for cultivating the "three sisters" companion crops: squash (*Cucurbita* spp.), maize (*Zea mays* L.), and beans (several genera in Fabaceae). Mounds of maize were planted first. After the plants grew approximately six inches in height, the other two crops were planted at the base of the cornstalks. The corn provided a trellis for the climbing beans, the beans added nitrogen to the soil, and the squash vines reduced weed competition. The three sisters were a staple throughout North America. Other important crops are listed in Table 5.1.

Medicinal herbs were collected from the wild and considered sacred by many tribes. They were often prescribed in conjunction with prayers, chanting, or ceremonies to speak with the spiritual realm. Southwest tribes used mescal beans from *Dermatophyllum* spp. as a hallucinogen. The beans do not contain mescaline, but they do contain hallucinogenic quinolizidine alkaloids. Four plants were commonly used during smudging (cleansing

Table 5.1 Crops originating in North America.

Fruits and vegetables		**Grains and legumes**	
Blueberry	*Vaccinium* spp., Ericaceae	Sunflower	*Helianthus annuus* L., Asteraceae
Cranberry	*Vaccinium macrocarpon* Aiton, Ericaceae	Wild rice	*Zizania* spp., Poaceae
Huckleberry	*Vaccinium* and *Gaylussacia* spp., Ericaceae	**Sweeteners and flavorings**	
Jerusalem artichoke	*Helianthus tuberosus* L., Asteraceae	Maple syrup	*Acer saccharum* Marshall., Sapindaceae
Pawpaw	*Asimina triloba* (L.) Dunal, Annonaceae	Sassafras	*Sassafras albidum* (Nutt.) Nees, Lauraceae
Prickly pear	*Opuntia* spp., Cactaceae	**Stimulants**	
Raspberry	*Rubus* spp., Rosaceae	Tobacco	*Nicotiana tabacum* L., Solanaceae

smoke) ceremonies: tobacco (*Nicotiana tabacum* L.), sweet grass [*Hierochloe odorata* (L.) P.Beauv.], sage (*Salvia apiana* Jeps. or other North American *Salvia* spp.), and cedar (*Juniperus virginiana* L., *Thuja plicata* Donn ex D.Don, or *T. occidentalis* L.). Some tribes would use red willow bark (*Cornus amomum* Mill.), compass plant (*Silphium laciniatum* L.), and/or osha root (*Ligusticum porteri* J.M.Coult. & Rose). In addition to smudging, tobacco was used for wound dressings, toothache relief (chewing tobacco), and as a general painkiller. It was only smoked occasionally for special medical and ceremonial purposes. When tobacco was taken back to Europe by early explorers, it was promoted as a cure-all. Early American settlers grew tobacco as a cash crop. It was not until the early 1800s that scientists discovered nicotine along with the addictive and detrimental effects of habitual tobacco consumption. It is still widely cultivated in North America today (Figure 5.2).

Bark of the Pacific yew (*Taxus brevifolia* Nutt.) contains the diterpene taxol, an effective anticancer agent. The berries were used in traditional medicine as birth control; other parts were used for hair removal and a range of ailments. The needles were reportedly smoked, causing dizziness (Bolsinger and Jaramillo, 1990). Native Americans used mayapple (*Podophyllum peltatum* L.) root as an emetic and antihelminthic agent. The lignan podophyllotoxin is the active component, sold as a topical pharmaceutical for warts. The Omaha tribe used pleurisy root (*Asclepias tuberosa* L.) as an expectorant for bronchitis. It contains pregnane glycosides that may be responsible for its medicinal properties. Oswego tea (*Monarda didyma* L.) was another botanical cold remedy. It was used as a tea replacement after the Boston Tea Party of 1773. Purple coneflower [*Echinacea purpurea* (L.) Moench.] was used for a wide range of ailments including insect and snake bites, burns and wounds, stomach ailments, and as a general "detoxicant."

Several North American nuts provided high-fat dietary sustenance such as hickory (*Carya* spp.), pecans [*Carya illinoinensis* (Wangenh.) K.Koch], piñon nuts (particularly from Great Basin *Pinus* spp.), American chestnut [*Castanea dentata* (Marshall) Borkh.], black walnut (*Juglans nigra* L.), and acorns (*Quercus* spp.). Maple syrup is derived from the sap of *Acer saccharum* Marshall (Figure 5.3). Native Americans had knowledge of

Figure 5.2 North American farm growing corn (*Zea mays*) and tobacco (*Nicotiana tabacum*).

Figure 5.3 Cross section of a sugar maple (*Acer saccharum*) with spiles or tapping spouts. The red arrow indicates one of the many places where the tree had been tapped.

maple syrup before the arrival of the Europeans, but it is unclear if they boiled down the sap to produce maple sugar. French colonists and missionaries may have introduced these techniques. By the late 1700s, maple sugar was sold commercially and promoted by Quakers and abolitionists to protest the use of slaves in white cane sugar production. Today the process of producing maple syrup has advanced from tin cans and metal spouts to vacuum pumps and tubing systems. Yet many small farmers still use the traditional metal spout and can method.

Wild berries were important to the health of Native Americans. In 1615, Samuel de Champlain observed Algonquin women drying a type of blueberry in the sun. They used these berries to make bread with cornmeal and beans, "manna in winter" when other food was scarce (Hummer 2013). They used cranberries (*Vaccinium macrocarpon* Aiton) (Figure 5.4), blueberries (*V. corymbosum* L., *V. angustifolium* Aiton) (Figure 5.5), and other *Vaccinium* spp. as food, dye, and medicine. In his writings, American botanist John Bartram described an Iroquois woman and her children drying huckleberries over a smoky fire. Henry David Thoreau stated that whortleberries were a major food source for Native Americans, sustaining them through thousands of years. Some tribes used *Vaccinium* berries as ceremonial food and medicinally as a health-promoting tea, for gastrointestinal and gynecological problems, and for children's health. The Newberry Crater archeological site located in central Oregon has produced a wealth of information about Paleolithic Native Americans. Pollen and phytolith analysis at the site revealed the presence of chokecherry [*Prunus virginiana* var. demissa (Nutt. ex Torr. & A.Gray) Torr.], salmonberry (*Rubus spectabilis* Pursh), thimbleberry (*Rubus parviflorus* Nutt), raspberry [*Rubus idaeus* subsp. *strigosus* (Michx.) Focke], blackberry (*Rubus* spp.), huckleberry, (*Vaccinium* spp.), and possibly currants (*Ribes* spp.) (Hummer 2013).

Native Americans used sassafras [*Sassafras albidum* (Nutt.) Nees] as flavoring and medicine. The roots are the basis of root beer flavor and are an important seasoning in Cajun and Creole gumbos. Some sources say the word *gumbo* is derived from the

Figure 5.4 Harvested cranberries (*Vaccinium macrocarpon*) floating in a bog in New England, the United States © 2015 Mary Ann Lila.

Figure 5.5 Wild blueberries (*V. angustifolium*) are typically smaller and darker than highbush (*V. corymbosum*) or rabbiteye (*V. virgatum*) blueberries. © 2006 Mary Ann Lila.

Choctaw (tribe native to Louisiana) name for sassafras, *kombo* (Buisseret and Reinhardt 2000). But early French texts such as Baudry des Lozières's *Second Voyage À La Louisiane* (1803) mentioned gumbo as the West African Bantu word for okra (*ki ngombo* or *quingombó*). Both groups were used as slave labor in the south, so it is possible the two groups shared knowledge and developed their own versions of gumbo together. The Meskwaki tribe reportedly used Indian turnip [*Arisaema triphyllum* (L.) Schott], also called Iroquois breadroot or Jack-in-the-pulpit, to poison their enemies. The corm contains large amounts of calcium oxalate that produces a burning, needle-like sensation when ingested. Dried and aged corms evidently contain less calcium oxalate, as they were ground and baked in bread. The dried corms were also taken as a treatment for coughs and colds and applied topically as a poultice for sores, inflamed joints, and snakebites.

Central America and the Caribbean

Mesoamerica is the cultural region extending from central Mexico south to Costa Rica. It included several advanced pre-Columbian societies such as the Olmec, Teotihuacan, Maya, and Aztecs (Nahuatl language groups). By 7000 BCE, Mesoamericans were domesticating maize, beans, squash, chili peppers (*Capsicum annuum* L.) and other crops (Table 5.2), changing societies from hunter-gatherer to simple farming villages.

Archaic period archeological sites throughout southern Mexico contain evidence of domesticated maize, squash, and beans. Pollen and cob remains from teosinte, the ancient progenitor to maize, date back to c. 9000 BCE. Fully domesticated maize appeared around 4000–3600 BCE, according to carbon dating (Pipierno and Flannery 2001; Kraft *et al.* 2014). Squash was domesticated c. 4000–4400 BCE. The common bean (*Phaseolus vulgaris* L.) was domesticated in southern Mexico c. 5000–3500 BCE and independently in the Andes of South America. There may have been some

Table 5.2 Crops originating in Central America or the Caribbean.

Fruits and vegetables		**Grains and legumes**	
Bottle gourd	*Lagenaria siceraria* (Molina) Standl., Cucurbitaceae	Beans	Fabaceae species
Chili peppers	*Capsicum* spp., Solanaceae	Cotton	*Gossypium hirsutum* L., Malvaceae
Culantro	*Eryngium foetidum* L., Apiaceae	Maize	*Zea mays* L., Poaceae
Dragonfruit	*Hylocereus* spp., Cactaceae		
Guava	*Psidium guajava* L., Myrtaceae	**Medicines, resins, dyes, and flavorings**	
Jicama	*Pachyrhizus erosus* (L.) Urb., Fabaceae	Chicle	*Manilkara chicle* (Pittier) Gilly Sapotaceae
Passionfruit	*Passiflora edulis* Sims, Passifloraceae	Copal	*Bursera* spp., Burseraceae
Papaya	*Carica papaya* L. Caricaceae	Fustic	*Maclura tinctoria* (L.) D.Don ex Steud., Moraceae
Squash	*Cucurbita* spp., Cucurbitaceae	Peyote	*Lophophora williamsii* (Lem. ex Salm-Dyck) J.M. Coult, Cactaceae
Star apple	*Chrysophyllum cainito* L., Sapotaceae	Vanilla	*Vanilla planifolia* Jacks. ex Andrews, Orchidaceae
Tomatillos	*Physalis philadelphica* Lam., Solanaceae		

Figure 5.6 Immature avocado (*Persea americana*) fruit.

hybridization with *P. coccineus*, resulting in larger bean sizes in Mesoamerican varieties. Avocado (*Persea americana* Mill; Figure 5.6) remains were found in a cave in Coxcatlán, Puebla, Mexico, dating to 10,000 BCE, but domestication likely occurred closer to 5000 BCE. Some believe California was its northern range; however, the US avocado industry did not get off the ground until the 1900s. Up until then, the fruit was known by its Spanish name, *ahuacate*, derived from the Nahuatl word *ahuacatl*, meaning “testicle.” A California growers association formerly changed the name to avocado. The popular ‘Hass’ cultivar is named after Rudolph Hass, who purchased the industry-changing seedling from a California farmer in 1926.

Chili peppers (Figure 5.7) were domesticated in northeastern Mexico and/or east central Mexico c. 4000 BCE (Kraft *et al.* 2014). *C. annuum* is one of five domesticated species of *Capsicum* native

Figure 5.7 *Capsicum annuum* varieties include hot chili peppers, mild bell peppers, and a range of peppers in between.

to the Americas, which include *C. baccatum* L., *C. chinense* Jacq., *C. fructescens* L., and *C. pubescens* Ruiz & Pav. In addition to food and flavoring, *Capsicum* peppers were used medicinally to treat asthma, coughs, convulsions, dysentery, liver disease, toothache, and skin diseases. Tomatillos (*Physalis philadelphica* Lam.) were domesticated in southern Mexico by the Mexica people c. 800 BCE and remain a staple in Mexican cuisine. Cilantro (*Coriandrum sativum* L.) is a herb frequently found in modern Mexican cuisine, but it is not native to Central America. Culantro (*Eryngium foetidum* L.; Figure 5.8) is native to Central and South America. It has a similar flavor to cilantro and a wide range of ethnomedical applications. Tomatoes (*Solanum lycopersicum* L.) are another staple in Mexican cuisine that is probably not native to the region. While their time and place of domestication is still uncertain, it most likely occurred somewhere in South America.

Figure 5.8 Culantro or recao (*Eryngium foetidum*) is a biennial herb with a flavor similar to cilantro (*Coriandrum sativum*).

There are several tropical fruits that originated in southern Mexico including guava (*Psidium guajava* L.) (Figure 5.9), papaya (*Carica papaya* L.) (Figure 5.10), and yellow passionfruit (*Passiflora edulis* Sims). Agave spp. were harvested for sweet sap and fiber (see Agave case study in the section titled “Agave: More Than Just Tequila” in Chapter 5). A species of vanilla orchid, *Vanilla planifolia* Jacks. ex Andrews, is native to Veracruz, Mexico. It is believed that the Totonac people were the first to cultivate vanilla (see vanilla case study in the section titled “Vanilla: Madagascar’s Orchid Economy” in Chapter 4).

Figure 5.9 Guava (*Psidium guajava*).

Figure 5.10 Papaya (*Carica papaya*)

Chicle, a sweet gum from *Manilkara chicle* (Pittier) Gilly, originated in Mesoamerica. Maya, Nahuatl, and undoubtedly other indigenous groups chewed chicle as a breath freshener and to quench thirst and hunger. American Thomas Adams created the modern chewing gum "Chicklets" from chicle after a brainstorming session with Mexican president Antonio Lopez de Santa Anna to use chicle as a type of vulcanized rubber. William Wrigley formed the William Wrigley Jr. Company, creating a massive demand for chicle in North America. By the 1930s, most of Mexico's chicle trees had been destroyed by unsustainable harvesting practices. Chewing gum companies switched to synthetic bases, destroying the chicle economy in Central America, but saving the remaining trees. American scientist Russell Marker used Mexican yams (*Dioscorea mexicana* Scheidw.) to synthesize progesterone from diosgenin in 1942, leading to the first birth control pill as well as synthetic testosterone, various estrogens, and cortisone.

Mesoamericans used tree resin primarily from *Bursera bipinnata* (Moc. & Sessé ex DC.) Engl. and other Burseraceae species called copal for incense, chewing, glue, paint binder, preservative, and medicine. Zinacantecos Mayans used resin from *Bursera excelsa* (Kunth) Engl., *B. tomentosa* (Jacq.) Triana & Planch., and *B. bipinnata* to fill tooth cavities and repair loose teeth. Huastec Mayans used *Bursera simaruba* (L.) Sarg. to treat burns, headache, nosebleed, fever, and stomachache and *Protium copal* (Schltdl. & Cham.) Engl. for fright, dizziness, and stomachache. The Lacandón Maya offered copal incense made from pitch pine (*Pinus pseudostrobus* Lindl.) to their gods. Chortí Mayans fashioned a maize cob out of *Bursera* copal to be placed in the granary to protect their harvest from harmful spirits. Several Mesoamerican communities smoked their maize seeds with copal smoke before planting as a form of spiritual protection. Mayans used smoke from *Bursera* copal to induce a trance-like hypnotic state in human sacrifices and shamans, although there are no known hypnotic or psychoactive compounds present.

Figure 5.11 Peyote cactus (*Lophophora williamsii*). © 2011 Amante Darmanin.

The peyote cactus [*Lophophora williamsii* (Lem. ex Salm-Dyck) J.M. Coult.] is native to the Chihuahua Desert in northern Mexico (Figure 5.11). Mescaline is the primary psychoactive alkaloid. It binds to serotonin receptors, affecting the frontal cortex, causing hallucinations. Native Americans used peyote in ceremonies, rituals, and for medicine. Likewise, morning glory seeds from several species in Convolvulaceae were used by Oaxaca Mexican tribes for divination, prophesy, and to treat illnesses. They contain ergoline alkaloids including the particularly hallucinogenic ergine, also known as lysergic acid (LSA). Mazatec shamans used *Salvia divinorum* Epling & Játiva, as its name implies, for divination. The diterpene salvinorin A is the active component. It is a potent κ opioid receptor agonist with no 5-HT2A serotonin receptor activity, the principal molecular target of classical hallucinogens (Roth *et al.* 2002).

Many of the crops and medicinal plants grown in the Caribbean were brought from Africa via the slave trade or by European explorers expanding their agricultural production (e.g., sugarcane and indigo). The Europeans decimated much of the forests for lumber and firewood, taking land away from native Caribs and Arawaks. Several native trees were used for timber including Caribbean mahogany [*Swietenia mahagoni* (L.) Jacq.], West Indian ebony [*Brya ebenus* (L.) DC.], walnut (*Juglans jamaicensis* C.DC.), and blue mahoe (*Hibiscus elatus* Sw.). The star apple (*Chrysophyllum cainito* L.) and Caribbean jujube soana (*Ziziphus rignonii* Delponte) are the only two endemic fruits valued for fresh consumption. Other native/naturalized fruit species from Central or South America include allspice [*Pimenta dioica* (L.) Merr.] (Figure 5.12), cashew (*Anacardium occidentale* L.) (Figure 5.13), annatto (*Bixa orellana* L.) (Figure 5.14), mammey (*Mammea americana* L.), soursop (*Annona muricata* L.), papaya, guava, and Jamaican plum (*Spondias purpurea* L.). Medicinal plants tend to be weedy, common species like *Dysphania ambrosioides* (L.) Mosyakin & Clemants and *Aristolochia trilobata* L. Several naturalized species such as the Pará rubber tree [*Hevea brasiliensis*, (Willd. ex A.Juss.) Müll.Arg.] from the Amazon, mango (*Mangifera indica* L.), and breadfruit [*Artocarpus altilis* (Parkinson ex F.A.Zorn) Fosberg] have historically been important crops.

Figure 5.12 Allspice (*Pimenta dioica*) leaf and fruit.

Figure 5.13 Cashew (*Anacardium occidentale*) has a pseudo-fruit "apple" born on top of the true cashew fruit, a kidney-shaped nut enclosed in a double shell containing irritating phenolic resin. © 2015 Maya Pujiati.

Figure 5.14 Annatto (*Bixa orellana*) fruit. Food coloring is obtained from a carotenoid-rich resinous coating on the seeds.

South America

Although there were hundreds of pre-Columbian native tribes living in South America, the Inca Empire was the largest and most sophisticated civilization in the New World. Centered in Peru's Cusco valley, the Inca Empire arose sometime between 1200 and 1300 CE and lasted until the Spanish eventually conquered them in 1572. In part, their rise to power is attributed to warming climate and terraced agriculture, leading to a surplus in maize. The Inca conquered the kingdoms in the Titicaca Basin, gaining a surplus of llamas and alpacas as draft animals, meat, leather, and fiber for clothing. More than 70 native crops were grown in their high-altitude agriculture including cotton, peanuts, peppers, potatoes, and yuca (cassava, *Manihot esculenta* Crantz). Cassava was domesticated c. 8000 BCE in western Brazil. There is evidence of cassava cultivation at Inca and Mesoamerican Mayan sites. The starchy roots can be cooked and consumed as a vegetable. When the root is dried and powdered, it is known as tapioca or manioc flour. Cassava starch can be used for baking, as a thickener, or sizing for fabrics. Potatoes (*Solanum tuberosum* L.) originated in the Andes and were domesticated between 8000 and 5000 BCE. The Incas cultivated over 200 varieties of potatoes. They produced a freeze-dried potato product called *chuño* that could keep for many months without spoiling. Table 5.3 provides a summary of crops that originated in South America.

Many plants were used for religious rituals or warfare by South American tribes. The Incas poured *Chicha de jora*, a fermented maize beverage, in the rivers as an offering to

Table 5.3 Crops originating in South America.

Fruits and vegetables		**Grains, legumes, and fiber**	
Brazil nut	*Bertholletia excelsa* Bonpl., Lecythidaceae	Beans	*Phaseolus* and other Fabaceae species
Cashew	*Anacardium occidentale* L., Anacardiaceae	Cotton	*Gossypium barbadense* L., Malvaceae
Cassava	*Manihot esculenta* Crantz, Euphorbiaceae	Peanut	*Arachis hypogaea* L., Fabaceae
Cherimoya	*Annona cherimola* Mill., Annonaceae	Quinoa	*Chenopodium quinoa* Willd., Amaranthaceae
Lúcuma	*Pouteria lucuma* (Ruiz & Pav.) Kuntze, Sapotaceae	Tonka beans	*Dipteryx odorata* (Aubl.) Willd., Fabaceae
Pineapple	*Ananas comosus* (L.) Merr., Bromeliaceae	**Stimulants and medicines**	
Potato	*Solanum tuberosum* L.	Coca	*Erythroxylum coca* Lam., Erythroxylaceae
Squash	*Cucurbita* spp., Cucurbitaceae	Cocoa	*Theobroma cacao* L., Malvaceae
Sweet potato	*Ipomoea batatas* (L.) Lam., Convolvulaceae	Guarana	*Paullinia cupana* Kunth, Sapindaceae
Tomato	*Lycopersicon esculentum* Mill., Solanaceae	Ipecac	*Carapichea ipecacuanha* (Brot.) L.Andersson, Rubiaceae
Dyes and latex		Jaborandi	*Pilocarpus* spp., Rutaceae
Annatto	*Bixa orellana* L., Bixaceae	Quinine	*Cinchona* spp., Rubiaceae
Rubber	*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg., Euphorbiaceae	Yerba mate	*Ilex paraguariensis* A.St.-Hil., Aquifoliaceae

the gods and consumed it during religious ceremonies. In sacred fields, crops were grown for the sole purpose of offering to the gods. Powdered bark resin from *Virola* spp. (Myristicaceae) trees were used to induce hallucinations in shamans. 5-MeO-DMT (5-methoxy-*N*,*N*-dimethyltryptamine) and DMT (*N*,*N*-dimethyltryptamine) are the psychoactive agents. Ayahuasca (Figure 5.15) is a South American concoction typically containing yagé vine [*Banisteriopsis caapi* (Spruce ex Griseb.) Morton], chaliponga [*Diplopterys cabrerana* (Cuatrec.) B.Gates] leaves, and/or chacruna (*Psychotria viridis* Ruiz & Pav.) leaves. The main active constituents of Ayahuasca are β-carboline harmala alkaloids and monoamine oxidase inhibitors from *B. caapi* and DMT from *D. cabrerana* and *P. viridis*. Sometimes *Brugmansia* sp. was added, contributing atropine, scopolamine, and hyoscyamine to the hallucinogenic mix. Curare is a generic term for isoquinoline or indole alkaloid arrow poisons. It can be prepared from *Strychnos* spp., *Chondrodendron tomentosum* Ruiz & Pav., and more than a dozen other species found in South America. d-Tubocurarine is the primary toxic compound. It is a muscle relaxant that was briefly used in anesthesia during the early twentieth century. San Pedro cactus [*Echinopsis pachanoi* (Britton & Rose) Friedrich & G.D.Rowley], and the Peruvian torch [*Echinopsis peruviana* (Britton & Rose) Friedrich & G.D.Rowley] contain mescaline and were used as hallucinogens throughout South America. Fruits from the sorcerers' tree [*Latua pubiflora* (Griseb.) Baill.] were used by Mapuche medicine men in Chile to induce delirium and hallucinations for medicinal purposes; hyoscyamine and scopolamine are responsible for the observed effects. In the Amazon, *Brunfelsia* spp. had a wide range of medicinal and hallucinogenic uses. *Brunfelsia* spp. contain the alkaloids manaceine, manacine, scopoletin, and the coumarin aesculetin.

The Amazon rainforest contains an abundance of biodiversity including important medicinal plants, some of which gained global importance. Cocaine from coca leaves (*Erythroxylum coca* Lam.), emetine from ipecacuanha rhizomes [*Carapichea ipecacuanha* (Brot.) L.Andersson.], pilocarpine from jaborandi (*Pilocarpus* spp.), and quinine

Figure 5.15 A pot of Ayahuasca. © 2015 Paul Hessell.

from *Cinchona* spp. bark are four well-known alkaloids with medicinal properties. Cocaine is a highly addictive recreational drug, but it also has been used as an anesthetic, analgesic, and to stop bleeding. Chewing coca leaves or drinking coca tea was and still is popular among native South American tribes for medicinal and religious purposes. Ipecacuanha has a long history of use as an emetic in South America. Up until the later part of the twentieth century, syrup of ipecac was prescribed throughout the world as a purgative for accidental poisoning. From the eighteenth to the twentieth centuries, it was used as an emetic and expectorant and mixed with opium to produce "Dover's powder," a common cold remedy (Figure 5.16). Pilocarpine from the bark of jaborandi trees is used in ophthalmology to relieve glaucoma pressure. "Jaborandi" is a Tupi word meaning "causes slobbering," describing its traditional and modern-day use as a treatment for dry mouth. Quinine is a well-known treatment for malaria that has made a colossal impact on the world of medicine and society as a whole. Native South Americans likely used cinchona or quina-quina bark long before the arrival of Europeans. Yet cinchona bark is sometimes called "Jesuit's bark" in reference to the Jesuit missionaries who used it to treat malaria during their missions to South America during the 1600s.

Figure 5.16 A bottle of Dover's Powder cold remedy: opium (*Papaver somniferum*) with ipecacuanha (*Carapichea ipecacuanha*). © 2014 Wellcome Library, London.

The Amazon rainforest is also the native habitat for the Pará rubber tree (*Hevea brasiliensis*). While native people used the natural latex for balls, shoes, and so on, for centuries, the vulcanization process developed in 1839 greatly increased its versatility, especially for industrial applications. The British Empire smuggled out seeds and eventually succeeded in growing rubber trees at their colonies in modern-day Singapore, Malaysia, Java, and Sri Lanka.

Yoco (*Paullinia yoco* R.E. Schult. & Killip), guarana (*Paullinia cupana* Kunth), yerba mate (*Ilex paraguariensis* A.St.-Hil.), and cocoa (*Theobroma cacao* L.) are four South American plants known for their stimulating properties. Xanthine alkaloids caffeine, theobromine, and theophylline are the active components. The Pre-Columbian Tupi and Guarani people of Paraguay and Brazil used guarana seeds and yerba mate leaves to make stimulating teas. Guarana seeds (Figure 5.17) are dried and pounded into a fine powder that can be added to teas, bread, and other foods. Yerba mate was primarily used as a stimulant and diuretic, but also for depression, pain, as an appetite suppressant, and topically as a poultice for ulcers. Yerba wildcrafters called *yerbateros* or *tarrafeiros* collect wild leaves that are said have superior flavor to plantation-grown yerba mate. The world produced over 4.5 million tons of cocoa beans in 2013 (FAO 2013). And while the top producers are not South American countries, the crop

Figure 5.17 Guarana (*Paullinia cupana*) fruit have black seeds covered by white aril. © 2012 Geoff Gallice.

originated in northern South America and Central America. The Latin name *Theobroma* means "food of the gods," and the species name *cacao* is derived from the Nahuatl word *xocolatl*, meaning "bitter water."

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Phlorotannins in Seaweed

(J. Kellogg)

Ethnobotany and Ethnopharmacology

Marine seaweeds have been traditionally harvested as a source of food, livestock fodder, and pharmaceuticals by coastal communities across the globe, especially those situated around the Pacific Rim (Widjaja-Adhi Airanthi *et al.* 2011). From arctic Alaska to the temperate Pacific Northwest, seaweeds have played a large role in the traditional cultures of multiple Native American/Alaska Native (NA/AN) and First Nation communities, including the Haida, Inuit, Tlingit, Tsimshian, Eyak, and Alutiiq peoples, as a ubiquitous source of macro- and micronutrients (Garza 2005; Turner and Bell 1973). Indigenous populations have harvested and consumed red, brown, and green seaweeds for generations, and these marine resources form an important part of the communities' traditional ecological knowledge.

Communities in Alaska's Bristol Bay region consumed *Fucus* spp. (Figure 5.18) and *Macrocystis* spp. covered with herring eggs as a springtime delicacy. First Nations in British Columbia prepare soups with species of the red alga *Porphyra* and clams, salmon

Figure 5.18 Fresh *Fucus distichus* ("bladder wrack" or "popweed") harvested near Whittier, Alaska, the United States.

eggs, or fish. The thalli (filaments of undifferentiated vegetative tissue) of red and brown algae, including *Porphyra* spp. and *Laminaria* spp., are dried and toasted to eat as a snack or sprinkled over other foods (Turner 2003). Seaweeds are also gathered and fermented to improve their shelf life for long-term use, then reconstituted as a soup flavored with oulachen oil (Turner and Bell 1973). To this day, nearly 60% of Inuit households among the Canadian Arctic's Belcher Islands regularly consume *Rhodymenia* spp. and *Laminaria* spp. (Wein *et al.* 1996).

In addition to their consumption as a part of traditional diets, brown and red seaweeds have been utilized as part of many communities' ethnomedical pharmacopeia. For example, hot baths of *Fucus* spp. were employed with yellow cedar boughs [*Chamaecyparis nootkatensis* (D.Don) Spach] in order to create a therapeutic steam to help cure bronchial infections and rheumatism (Boas 1966). In addition, *Fucus* were chopped and heated in conjunction with dried tobacco (*Nicotiana* spp.), alder bark (*Alnus rubra* Bong.), and twinberry cuttings [*Lonicera involucrate* (Richardson) Banks ex Spreng.] and applied as a poultice compress to relieve inflammation, aches, and pains (Turner and Bell 1973). Similarly, children with sores or itchy scabs were rubbed with *Fucus* thalli followed by catfish oil and burnt red ochre, or with strips of the brown seaweed *Nereocystis luetkeana* (K.Mertens) Postels & Ruprecht (Boas 1966). *N. luetkeana* was also applied externally to the stomach of a pregnant woman to ease childbirth, so that the child would become as slippery as the seaweed. The green seaweed *Ulva lactuca* L. was mixed with twinberry bark and applied to a woman's breasts after delivery to relieve soreness and inflammation (Turner and Bell 1973).

Chemistry and Bioactivity

Seaweeds, especially brown algae, have been shown to contain high levels of polyphenols, which can account for as much as 20% by dry weight of the seaweed (Ragan and Glombitza 1986). In brown seaweeds, the predominant polyphenols are a family of tannin-like structures known as phlorotannins, with nearly 150 unique phlorotannin structures identified that range from 126 Da to over 500 kDa (Martínez and Castañeda 2013). Phlorotannins are oligomeric constructs based upon the monomer phloroglucinol (1,3,5-trihydroxybenzene), which is biosynthesized via the polyketide pathway (Meslet-Cladière *et al.* 2013). The polymers are primarily stored in the thalli, and their composition and quantity exhibit internal, geographic, and temporal variability. The monomeric units are linked through aryl–aryl bonds and diarylether bonds, forming four phlorotannin subgroups differentiated by their means of linkage: phlorotannins with an ether bridge (fuhalols and phlorethols), with an aryl–aryl linkage (fucols), those with ether and phenyl links (fucophlorethols), and phlorotannins with a dibenzodioxin linkage (eckols and carmalols) (Glombitza and Pauli 2003) (Figure 5.19).

The myriads of phlorotannin structures in brown algae have demonstrated numerous bioactive properties. They have strong antioxidant activities against free-radical-mediated oxidation by scavenging radicals and inhibiting peroxidation (Shibata *et al.* 2008). Like terrestrial polyphenolic compounds, phlorotannins are also ubiquitous enzyme inhibitors that have been shown to modulate the activity of carbohydrate-hydrolyzing

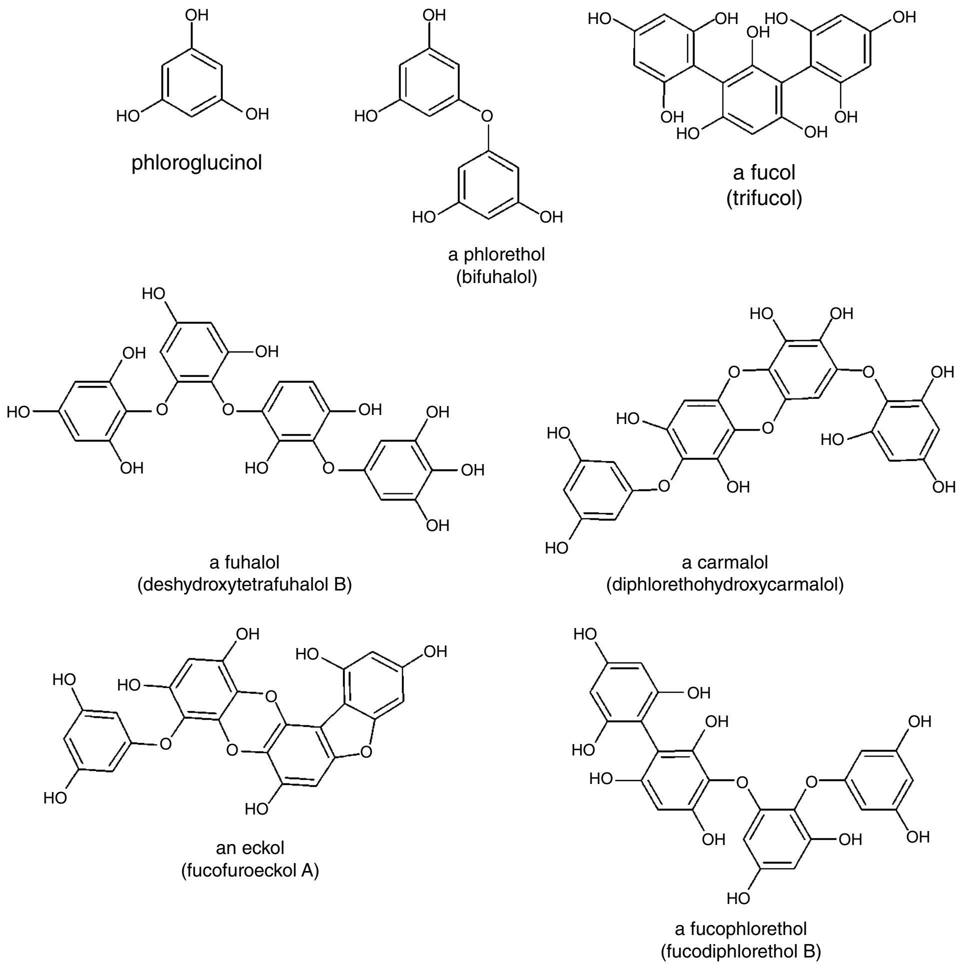

Figure 5.19 Structural classes of phlorotannins, oligomers of phloroglucinol.

enzymes α-glucosidase and α-amylase, thereby decreasing hyperglycemia (Eom *et al.* 2012), inhibiting the angiotensinogen-I-converting enzyme to regulate blood pressure (Jung *et al.* 2006), blocking the digestive enzyme lipase and lowering dyslipidemia (Eom *et al.* 2013), and arresting tyrosinase activity, preventing the synthesis of melanin and subsequent hyperpigmentation (Yoon *et al.* 2009). Furthermore, phlorotannins have exhibited strong anti-inflammatory properties, blocking production of pro-inflammatory cytokines such as prostaglandins and nitric oxide (Kim *et al.* 2009). In addition, phlorotannins have reduced growth of certain cancers, including MCF-7, HeLa, HT1080, A549, and HT-29 cells (Li *et al.* 2011). More recently, evidence has emerged that phlorotannins may reduce allergic reactions by blocking histamine release from basophils (Sugiura *et al.* 2006).

Modern Uses

Brown seaweed consumption around the globe remains a dietary source of phlorotannins. However, concentrated phlorotannin preparations have begun to be commercialized as ingredients within various health and beauty products. Commercial extracts of the brown algae prepared from *Ascophyllum nodosum* (L.) Le Jolis and *Fucus vesiculosus* L. are marketed to reduce postprandial serum glucose levels (Roy *et al.* 2011). Phlorotannins have also been incorporated into cosmeceutical formulations for their tyrosinase inhibiting (Thomas and Kim 2013) and anti-photoaging properties (Pallela *et al.* 2010). As such, they have efficacy in preventing the development of wrinkles and skin darkening, making them useful additives in skin-whitening creams and anti-wrinkle formulations (Thomas and Kim 2013). Marine-based phlorotannins hold great potential for continued development as nutraceutical supplements and other therapeutic formulations that impact multiple chronic human conditions.

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Agave: More Than Just Tequila

(B. M. Schmidt)

Ethnobotany

Agave is a genus of succulent plants with a geographic center of origin in Mexico (Good-Avila *et al.* 2006). Populations have spread north to the deserts of the southwestern United States, east into the Caribbean, and south to Central and South America. The genus was formerly placed in the family Agavaceae, but has since been moved to Asparagaceae. Perhaps the most well-known member of the genus is *Agave tequilana* F.A.C.Weber, the blue agave. It is native to Jalisco, Mexico, and is the primary ingredient in the alcoholic beverage tequila. To make tequila, the heart or *piña* of the plant is harvested around the twelfth year of growth by *jimadores*, Mexican agave farmers. Agave juice is extracted from the pulped *piña* (Figure 5.20) then fermented, distilled, and often aged to form tequila. Mescal is a similar distilled alcoholic beverage produced from *Agave parryi* Engelm. and other *Agave* spp.

Figure 5.20 *Jimadores* use a dried calabash gourd [*Lagenaria siceraria* (Molina) Standl.] called an *acocote* to suck *aguamiel* out of the center of an Agave stem. © 2012 Nacho Pintos.

Before the Spaniards arrived, native Mesoamericans did not have knowledge of distillation. For centuries, they consumed fermented beverages from *Agave* (locally called *maguey*) known as *pulque* (Figure 5.21). Murals in Teotihuacan (c. 150 BCE–650 CE) depict maguey plants and scenes of possible pulque consumption (Correa-Ascencio *et al.* 2014). Some speculate pulque served as probiotic medicine and a source of micronutrients in early Mesoamerica (Correa-Ascencio *et al.* 2014). Pulque was certainly an important element of many Mesoamerican rituals; both the Maya and Aztecs had pulque deities (Henderson 2008). To make pulque, a juice called *aguamiel* is collected from the center of *A. americana* L., *A. salmiana* Otto ex Salm-Dyck, *A. sisalana* Perrine, or other *Agave* species and fermented to a milky, viscous liquid with a short shelf life. The short shelf life meant that Mesoamericans often drank to the point of vomiting during ceremonies, as to not let any go to waste. But ethnobotanists also speculate vomiting from pulque was viewed as a cleansing necessary to communicate with the gods (Henderson 2008).

A. sisalana is also the source of sisal, a fiber used for rope, twine, nets, baskets, and clothing. The Aztecs and Mayans extracted the fibers for use as rough garments and used the spines as needles. Sometimes it is referred to as the "needle and thread plant." Sisal fibers were originally exported from the port of Sisal in the Yucatan, but the plant does not grow in that region. Yucatan farmers instead have fiber plantations growing *A. fourcroydes* Lem. for henequen production. Henequen is a similar type of fiber but considered lower quality than sisal. It is primarily used for burlap bags, ropes, and mooring. The most likely place of origin for *A. sisalana* is the neighboring state of Chiapas, where farmers grow it as fencerows and for fiber. Each plant will produce about 220 leaves before bolting at around seven years of age. If leaves are regularly harvested, bolting may be delayed for 15–20 years. After bolting, the plant dies. Under the hot and dry native conditions in Mexico, *A. sisalana* produces around one ton of dried fibers per hectare. In East Africa, especially regions in Kenya and Tanzania with much higher annual rainfall than Mexico, yields of dry fiber can reach two to five tons per hectare.

The namesake of *A. sisalana*, Dr. Henry E. Perrine, was a French doctor from New Brunswick, New Jersey, appointed as US Consul at Campeche, Yucatan in 1827. He made extensive plant collections, many of which can be found at the New York Botanical Gardens today. In 1838, Congress awarded him a six square mile plot of land on lower Biscayne Bay south of Miami, Florida, for the propagation and cultivation of tropical plants. He and his family first settled on Indian Key, where he had sent many of his plant and seed specimens for safe keeping until the end of the Seminole War. Unfortunately, on August 7, 1840, several canoes of Seminoles landed on the shores and began a nighttime siege on the outpost (Perrine 1885). Dr. Perrine was killed, and many of his specimens destroyed. A few survived, including *A. sisalana*, some date palms, and wild limes, known as "key lime" today (Robinson 1937). About 50 years later, sisal became important as binder or reaper twine for US agriculture. Mexico banned export of plants for cultivation and enjoyed a brief but profitable monopoly. But American horticulturists had Perrine's stock of wild *A. sisalana* and were soon able to produce thousands of plants. In 1893, 1000 bulbils were sent from Florida to Germany and onward to Tanzania (Brown 2002). The 62 plants that survived started large plantations in East Africa. Around 1919, the United States Sisal Trust was formed to start commercial production in Florida (Brown 2002). They imported 220,000 tons of *A. sisalana* from Mexico and the Caribbean to grow on huge plantations in Dade County. Production eventually waned owing to the introduction of synthetic fibers after World War II and unsuitable environmental conditions such as hurricanes.

Figure 5.21 Bottle of pulque in Zacatlán, Puebla, Mexico. © 2015 Alejandro Linares Garcia.

Phytochemistry

Alcoholic beverage production from *Agave* spp. relies on fermentation of the plant sugars, mostly fructose. In contrast to beer and wine, which rely heavily on yeast for fermentation, pulque is primarily produced by bacterial fermentation. Reported species include dextran-producing lactic acid bacteria such as *Leuconostoc* (Correa-Ascencio *et al.* 2014; Escalante *et al.* 2008). Dextran, a branched glucose polysaccharide from 3–2000 kDa, is largely responsible for the viscous texture of pulque. Dextran along with several micro/macronutrients and lactic acid bacteria are thought to be both pre- and probiotic for gut bacteria (Correa-Ascencio *et al.* 2014). The presence of phytase would have helped Mesoamericans better digest maize by increasing the bioavailability of iron, phosphorous, and zinc (Correa-Ascencio *et al.* 2014).

Sisal (and henequen) fibers are removed from mature *Agave* leaves cut off at the base of the stem. The leaves are squeezed between two large rollers to press out the water and turn the soft tissues into a pulp that can be scraped away from fibers. Fibers account for only 4% of the harvested biomass; the remaining pulp is an agricultural waste that has recently been evaluated for use as mulch, animal feed, or biofuel (Machin 2008). After pulp removal, sisal fibers are washed and hung in the sun to dry. The result is a creamy white fiber up to one meter in length. Scanning electron microscope (SEM) micrographs of fiber strand cross sections reveal bundles of about 100 hollow cellulosic sub-fiber cells that run the length of the fiber strand (Fávaro *et al.* 2010, Lacerda *et al.* 2013). These individual fibers are 1.0–1.5 cm in length, 100–300 μm in diameter (Fávaro *et al.* 2010), and primarily composed of cellulose (~70%). A middle lamella composed of hemicellulose, lignin, and pectin link the fiber cells together (Figure 5.22).

While cellulose is only composed of glucose, hemicellulose is a heterogeneous molecule, composed of an assortment of sugar monomers in a random, branched pattern. Hemicellulose retains water (a disadvantage in composites), and even though lignin is the "glue" that attaches the cellulosic bundles, it can be a source of weakness in composites. Therefore, hemicellulose and lignin are typically removed by mercerization with alkali or

(A)

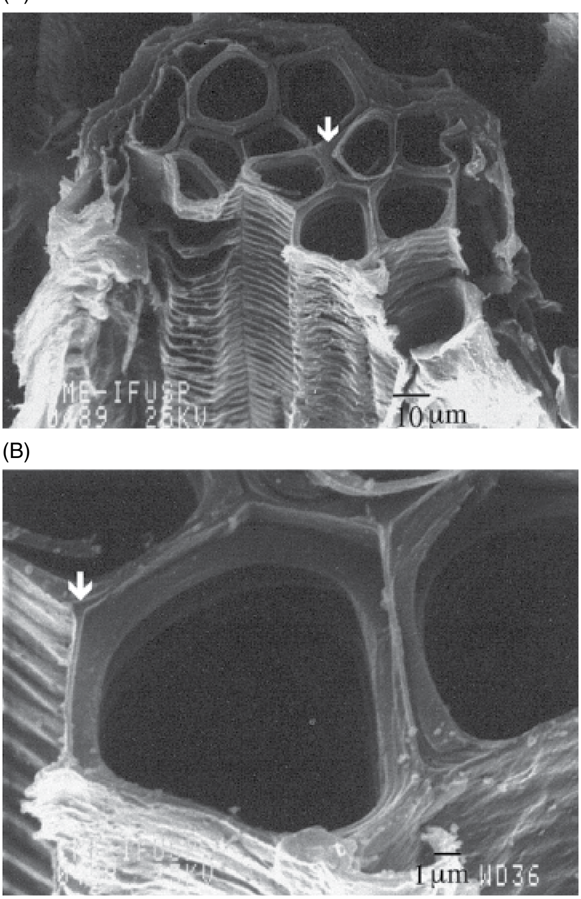

Figure 5.22 SEM micrograph (scale bar = 10 μm) of sisal fiber conductive vessels (A). Micrograph (B) (scale bar = 1 μm) is a detail of (A). The arrows show the middle lamella. Martins *et al.* 2004. Reproduced with permission of John Wiley & Sons, Ltd.

by hydrothermolysis before creating the composite (Brouwer 2000). Mercerization also improves the fiber tensile strength dimensional stability, elasticity, uniformity, and the success of binding cellulose fibers to polymer monomers (Khan *et al.* 2005). The fibers must be dried to 2–3% moisture before mixing with thermoplastic polymers (Brouwer 2000). After the sisal fibers and thermoplastic are mixed and molded, they are often cured with UV radiation (Khan *et al.* 2005).

Compared to glass composites such as fiberglass, sisal composites are only half as strong, but they are also less dense. When accounting for density, their tensile strength is similar. Their impact strength is less than fiberglass, but three times higher than polyester composites and higher than other natural fibers like coir, banana, and pineapple (Joseph *et al.* 1999). New developments in thermoplastic technology and fiber modifications have greatly improved composite mechanical properties (e.g., impact and tensile strength), making sisal composites competitive with fiberglass and other similar materials (Fávaro *et al.* 2010).

Modern Uses

According to the Distilled Spirits Council of the United States, the United States imported 13.8 million 9 L cases of tequila in 2014. This accounts for roughly 52% of global sales. Pulque is still consumed throughout Mexico (Figure 5.23) and is gaining popularity with Mexico's youth at century-old "pulquerias" in Mexico City.

Currently, sisal fiber is produced in East Africa, Brazil, Haiti, India, and Indonesia. Mexico no longer produces much sisal, but henequen production continues in the Yucatan region. Several German automobile companies, including Audi, BMW, and Mercedes-Benz, use sisal textiles and mats, and sisal fiber composites for body panels and trim. The

Figure 5.23 Pulque vendor in Zacatecas, Mexico. © 2007 Tomas Castelazo.

composites have high strength and impact resistance while reducing the overall weight and cost of the vehicle. The Lotus Eco Elise contains several different natural fibers including wool, hemp, and sisal. In civil engineering, sisal can be used in building materials (panels, floor tiles, etc.) as a low-cost and eco-friendly alternative to materials like fiberglass.

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Quinoa: A Source of Human Sustenance and Endurance in the High Andes

(B. L. Graf)

Ethnobotany and Ethnopharmacology

Quinoa (*Chenopodium quinoa* Willd., Amaranthaceae) (Figure 5.24), a South American subsistence crop, has been cultivated for over 5000 years in the Andes Mountains up to 4500 m in altitude among the modern-day countries of Argentina, Bolivia, Chile, Colombia, Ecuador, and Peru (Cusack 1984; Dillehay *et al.* 2007; Fuentes *et al.* 2009; Vega-Galvez *et al.* 2010). Quinoa was a sacred staple crop of the ancient Incas (Cusack 1984) and continues to be utilized by the Quechua, Aymara, Tiahuancota, Chibcha, and Mapuche indigenous peoples (Bhargava and Srivastava 2013; Vega-Galvez *et al.* 2010). In many regions of the Andean Altiplano, quinoa is the only crop viable for cultivation under the extreme environmental conditions, characterized by high altitude, low rainfall, arid climate, saline soils, intense temperature fluctuations, and high ultraviolet radiation (Figure 5.25) (FAO 2011; Hellin and Higman 2003; Vega-Galvez *et al.* 2010).

Traditionally, quinoa has been used as a wellness-promoting and endurance-enhancing food, especially directed toward vulnerable populations such as children and the elderly (FAO 2011; Gorelick-Feldman *et al.* 2008; Kokoska and Janovska 2009; Lafont 1998; NRC 1989). Quinoa seeds are typically consumed similarly to rice: prepared in soup, puffed to make breakfast cereal, or ground to flour to produce toasted and baked goods (Bhargava 2006; NRC 1989). "Llipta," the pungent ash of quinoa stems, mixed with the leaves of the coca plant (*Erythroxylum coca* Lam.), has been chewed by Andean farmers to sustain their energy during hard labor (Martindale 1894). Furthermore, the Incan armies were sustained for days as they marched over the Andes Mountains by a mixture of quinoa and fat called "war balls" (Small 2013). Due to these traditional uses, quinoa may be considered an "adaptogen." Adaptogens are defined as agents that reduce stress-induced damage (e.g., anti-fatigue, anti-depressant) and exhibit stimulating effects (e.g., increased working capacity) within a stressful context without depleting energetic resources or perturbing normal bodily functions (Panossian and Wikman 2009, 2010; Brekhman and Dardymov 1968).

Figure 5.24 A red variety of *Chenopodium quinoa* Willd. (quinoa). © 2014 David Wu.

Figure 5.25 A quinoa field in the Aymara village of Ancovinto, Tarapacá, northern Chile, a village situated 3681 m above sea level that receives less than 200 mm of rainfall annually. January 2013.

Chemistry and Bioactivities

Quinoa has been shown to contain two major classes of biologically active compounds that likely play a role in its adaptogenic properties: phenolics and phytoecdysteroids. Phenolics, mainly flavonoid glycosides (Figure 5.26A) and phenolic acids (Figure 5.26B), are biosynthesized through the shikimate pathway, yielding total levels as high as 3996 µg/g seed (Gomez-Caravaca *et al.* 2011). Phytoecdysteroids, among which 20-hydroxyecdysone (20HE) (Figure 5.26C) is most abundant of 13 different analogs (Kumpun *et al.* 2011), are biosynthesized through the melavonate pathway with total levels as high as 570 µg/g seed (Adler and Grebenok 1995; Graf *et al.* 2016).

Phenolics and phytoecdysteroids are thought to be the major bioactive constituents of the traditional "adaptogenic" herbs such as *Rhaponticum carthamoides* (maral rool or Russian *Leuzea*) (Brekhman and Dardymov 1968; Panossian and Wikman 2009, 2010) and *Ajuga turkestanica* (sanabor) (Arthur *et al.* 2014). Flavonoid, phenolic acid, and phytoecdysteroid-containing extracts of *R. carthamoides* have exerted significant positive effects on running and swimming endurance, working capacity, rehabilitation from intense physical activity, and mental capacity (learning and memory) in animal and human clinical trials (Kokoska and Janovska 2009). Phytoecdysteroid-enriched extracts of *A. turkestanica* have been shown to stimulate protein synthesis in muscle cells (Gorelick-Feldman *et al.* 2008) and promote muscle integrity in aged mice (Arthur *et al.* 2014).

Individual phenolics and phytoecdysteroids have demonstrated a range of biological activities in mammals that may contribute to the endurance- and wellness-promoting effect of quinoa consumption (Dinan 2009; Dinan and Lafont 2006; Klein 2004). Phenolics are particularly renowned for their anti-inflammatory and immunomodulatory

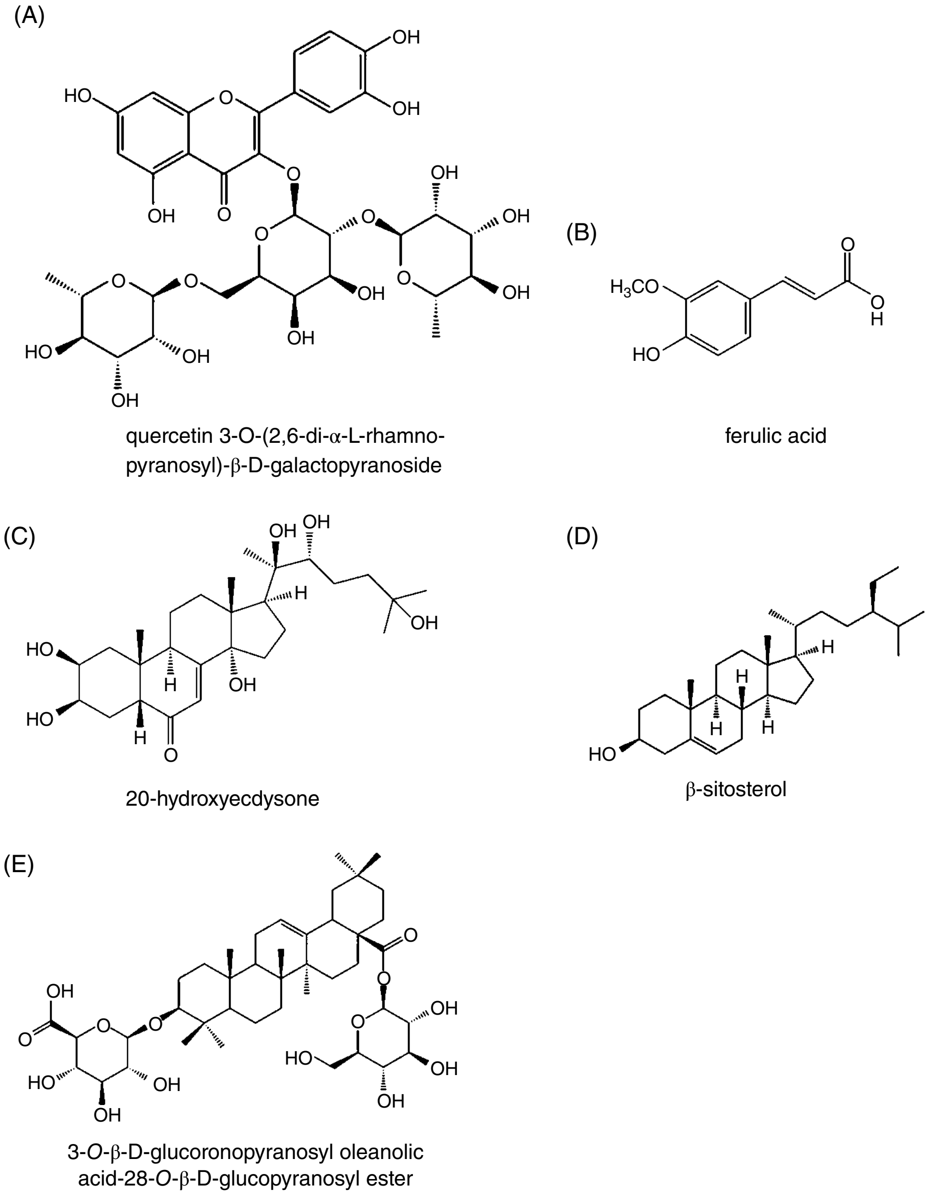

Figure 5.26 Examples of biologically active compounds in quinoa from five classes of molecules: (A) flavonoid glycoside, (B) phenolic acid, (C) phytoecdysteroid, (D) phytosterol, and (E) saponin.

capacities. Quercetin, the most widely studied phenolic, reduced expression of inflammatory genes in human macrophages and adipocytes, protected β-cells from oxidative damage, reduced lipid peroxidation, and prevented myocardial infarction in rats, lowered circulatory inflammatory risk factors in mice, and lowered blood pressure in hypertensive humans (Russo *et al.* 2012). Meanwhile, isolated phytoecdysteroids have been shown to reduce stress-induced reactive oxygen species production in human cells

(Graf *et al.* 2014), accelerate wound healing (Syrov and Khushbaktova 1996), promote growth, and enhance working capacity in animals (Cheng *et al.* 2013; Gorelick-Feldman *et al.* 2008; Syrov *et al.* 2008). Both phenolics and phytoecdysteroids have also demonstrated anti-diabetic, hepatoprotective, neuroprotective, anti-cancer, and antioxidant properties in vitro and in vivo (Dinan 2009; Dinan and Lafont 2006; Klein 2004). Other phytochemical constituents of quinoa seeds, including phytosterols (Figure 5.26D) and saponins (Figure 5.26E), have been hypothesized to potentiate the biological activities of phenolics and phytoecdsyteroids by promoting their cellular bioavailability (Klein 2004), though further research is needed to determine the interactions and possible synergistic effects of these molecules.

Modern and Prospective Uses

Over the past few decades, quinoa production and consumption has expanded from its traditional cultivation regions in the Andes to Africa, Asia, Europe, and North America, thereby offering nutritional benefits worldwide (Bhargava *et al.* 2006). Global research and development of quinoa was promoted in 2013 by the United Nations' program entitled the "International Year of Quinoa" (FAO 2011). Novel means of incorporating the seeds in the diet have been developed to increase the market appeal and convenience of quinoa consumption, such as quinoa-containing fruit compotes and energy bars (Figure 5.27). Furthermore, numerous methods to concentrate and/or deliver bioactive components from quinoa have been invented and commercialized for therapeutic uses (Bhargava *et al.* 2006; Graf *et al.* 2014b). For example, phytoecdysteroid-enriched extracts and purified saponins have been implicated in weight loss and drug absorption

Figure 5.27 Ecuadorian fruit compote for children. © 2013 Cancillería del Ecuador.

applications, respectively (Estrada *et al.* 1997; Foucault *et al.* 2011; Msika 2012; Scanlin and Stone 2008; Veillet and Lafont 2012). Recent clinical research has shown potential for quinoa to play a role in the prevention of metabolic disease (De Carvalho *et al.* 2014) and the promotion of childhood growth and nutrition (Ruales *et al.* 2002). However, clinical trials have not yet assessed the potential adaptogenic effects of quinoa products, such as enhancement of mental performance under stress or improved recovery following intense physical activity. Since numerous in vitro and in vivo studies have demonstrated the stress-reducing and performance-enhancing properties of quinoa's phytochemical constituents, (Kokaska *et al.* 2009), ongoing investigations may show quinoa to be an effective adaptogen.

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Maqui (*Aristotelia chilensis*): An Ancient Mapuche Medicine with Antidiabetic Potential

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Maqui in the Mapuche Culture and Traditional Medicine

The Mapuche people are native inhabitants of Southern Chile and Argentina. They are currently the major native ethnic group in Chile with over 300,000 people concentrated in the Araucanía Region. This nation of fearless warriors kept both the mighty Inca Empire and the powerful Spanish conquistadors at bay for centuries. The Mapuche medicine system is based on sacred rituals and herbal preparations dating back hundreds of years. The federal government actively supports traditional Mapuche medicine; it has been formally introduced as part of the regular local public health care system in Chile (Ladio and Lozada 2000). For Mapuches, their traditional medicine is part of a holistic view of the universe, in which health and illness are closely linked and balanced in harmony. Thus, all human actions affect this balance (Albornoz *et al.* 2004), and concepts like health, physical wellness, or disease are dynamically linked (Grebe 2006). The "Machi" is the spiritual leader; a priestess who is able to heal, provide spiritual guidance, communicate with the deities, and ward off evil spirits. She is responsible for healing and bridging the community with the "ngen" (the guardian spirits) (Mujica *et al.* 2004). During the healing rituals, the Machi conveys religious and mythological beliefs (Grebe 1995) and combats the symptoms but not the cause of the

Figure 5.28 Maqui fruits. © 2014 Belén Jara.

diseases. In order to do this, she goes into a trance in which she deals with the disturbing spirits and finds the exact remedy to restore the spiritual balance and well-being of an ill person, especially through the use of herbal teas, poultices, and ointments (Echeverría *et al.* 2002).

According to Mapuche beliefs, all plants have medicinal properties. Their word *lawen* means both "plant" and "remedy" (CONAMA 2008). They consider maqui (*Aristotelia chilensis*, Figure 5.28) as not only a medicinal plant but also a symbol of prosperity for Mapuche people. *A. chilensis* is an endemic Chilean plant that belongs to the Elaeocarpaceae family. The fruit is a fleshy, glossy, purplish to black, round berry (Madaleno 2007). This dioecious plant blooms between the months of October to December. It can be found in the Andes between latitudes 31° and 42°, especially in Chile's central valley and even on Juan Fernandez Island (Rodríguez *et al.* 1983). The Mapuche people usually refer to the groves of maqui plants that grow in wet soil or near streams as "macales." This resilient plant, unlike many other species, is capable of growing rather easily in extremely harsh environments like burned lands and deforested areas. Perhaps this is why maqui is considered a living symbol of a resilient species (Hoffmann *et al.* 1992).

In Mapuche traditional medicine, an infusion of maqui leaves is used to heal wounds, reduce fever, treat diarrhea and stomachaches, calm sore throats and swollen tonsils, and to heal oral ulcers (Madaleno and Gurovich 2004; Villagran *et al.* 1983). Mapuche midwives give women infusions of maqui leaves to facilitate childbirth (Alarcón and Nahuelcheo 2008). Maqui berries can be eaten fresh or dry, in the form juice, jam, or a fermented liquor (locally known as *techu*). Ethnomedical records indicate that the natives from Southern Chile used maqui fruit to treat skin inflammation, intestinal disorders, sore throats, infected wounds, dietary fiber, hemorrhoids, and migraines (Molgaard *et al.* 2011; Ojeda *et al.* 2011; Píriz 2013; Schreckinger *et al.* 2010). Maqui is also used by Mapuches to make wooden souvenirs and to handcraft musical instruments. According to Mapuche traditional knowledge, carvings made out of selected maqui wood have unique pleasurable sounds (Quintriqueo *et al.* 2011).

Maqui plays an important role during Mapuche's sacred ceremonies like the *machitun* (healing ceremony) and the *nguillatun* (praying ceremony). In these rituals, branches of maqui, cinnamon leaves, and bay leaves are tied to the *rehue* (Figure 5.29) and thus offered by the Machi to the spirits. The rehue is a pole carved from "laurel" or other trees, and it is always the center of the nguillatun. It is through the rehue and the plants offerings that the Machi establishes a communication with spiritual world (Kraster 2003).

Figure 5.29 "Rehue" in Araucanía Region of Southern Chile. © 2014 Bernarda Calfío.

Chemistry and Ethnopharmacology

Several studies have described the chemistry and pharmacology of maqui (Table 5.4). Alkaloids, polyphenols, and anthocyanins have been identified as bioactive secondary metabolites in maqui leaves and fruit (Table 5.4). Maqui berry contains a low concentration of indole and quinoline alkaloids (Cespedes *et al.* 1993) and high concentrations of anthocyanins (137.6 mg/100 g fresh weight). Eight types of anthocyanins have been identified; delphinidin 3,5-O-diglucoside and delphinidin 3-O-sambubioside-5-O-glucoside are the most abundant (Escribano-bailón *et al.* 2006; Tanaka *et al.* 2013). Biochemical characterization of maqui leaves have revealed the presence of aristone, aristoteline, aristotelinine, and aristotelone, alkaloids unique to the genus *Aristotelia* (Schreckinger *et al.* 2010a; Zabel *et al.* 1980). A maqui leaf extract rich in

Table 5.4 Main phytochemical constituents reported in *Aristotelia chilensis*.

Phytochemical constituent	Plant organ	Reported bioactivity	Reference
Alkaloids			
8-Oxo-9-dehydrohobartine	Leaves	NBR[(*)]	Cespedes *et al.* 1990
8-Oxo-9-dehydromakomakine	Leaves	NBR	
Aristone	Leaves	NBR	Bittner *et al.* 1978
Aristotelinine	Leaves	NBR	
Aristotelone	Leaves	NBR	Bhakuni *et al.* 1976
Aristoteline	Leaves	NBR	
Phenolics			
Delphinidin-3-O-sambubioside-5-O-glucoside	Fruit	Antidiabetic Antioxidant Anti-apoptotic	Céspedes *et al.* 2010; Escribano-bailón *et al.* 2006; Gironés-Vilaplana *et al.* 2012; Rojo *et al.* 2012; Tanaka *et al.* 2013
Delphinidin-3,5-O-diglucoside	Fruit	Antioxidant Anti-apoptotic	
Cyanidin-3-sambubioside-5-glucoside	Fruit	Antioxidant	Escribano-bailón *et al.* 2006; Céspedes *et al.* 2010; Gironés-Vilaplana *et al.* 2012
Cyanidin-3-sambubioside-5-glucoside	Fruit	Antioxidant	
Cyanidin-3,5-diglucoside	Fruit	Antioxidant	
Delphinidin-3-glucoside	Fruit	Antioxidant	
Delphinidin-3-sambubioside	Fruit	Antioxidant	Escribano-bailón *et al.* 2006; Céspedes *et al.* 2010
Cyanidin-3-sambubioside	Fruit	Antioxidant	
Cyanidin-3-glucoside	Fruit	Antidiabetic Antioxidant Anticancer	Escribano-bailón *et al.* 2006; Gironés-Vilaplana *et al.* 2012; Marczylo *et al.* 2009

[(*)] NBR: No bioactivity reported.

alkaloids showed antiviral and nematicidal activity (Schreckinger *et al.* 2010a). Leaf extracts also induce alterations in the morphology of human erythrocytes from the normal discoid shape to an echinocytic form, an activity attributed to flavonoids (Suwalsky *et al.* 2008).

Maqui berry displays powerful antioxidant capacity, and protects against low-density lipoprotein oxidation and oxidative damage in cultured endothelial cells, suggesting an anti-atherogenic effect (Miranda-Rottmann *et al.* 2002). Polyphenol extracts from maqui berry have shown anti-inflammatory (Céspedes *et al.* 2010) and anti-adipogenenic effects (Schreckinger *et al.* 2010b). A crude extract from maqui berry was capable of inhibiting the activity of α-glucosidase and α-amylase, enzymes responsible for the intestinal degradation of complex carbohydrates into glucose (Rubilar *et al.* 2011). The same study suggested that catechin, epicatechin, quercetin, and kaempferol are responsible for this enzymatic inhibition. A recent study on diet-induced obese hyperglycemic mice suggested that delphinidin 3-sambubioside-5-glucoside (DSG) is the main bioactive anthocyanin responsible for the antidiabetic effect of maqui berry (Rojo *et al.* 2012). DSG displayed insulin-like effects in muscle and liver cells. Fuentes *et al.* (2013) proposed that maqui berry's hypoglycemic effect is due to the synergistic effect of anthocyanins, quercetin, and rutin. Collectively, these studies suggest that maqui polyphenols might have a prophylactic effect against metabolic syndrome by ameliorating hyperglycemia and hyperlipidemia. Although no ethnomedical records are available on maqui as an antidiabetic fruit, and the biochemical/pharmacological results have not yet been confirmed at the clinical level, there is one report that Mapuche children have a lower incidence of insulin-dependent diabetes than their Caucasian counterparts (Larenas *et al.* 1996). This epidemiological observation might be explained, in part, by a regular intake of maqui fruit. It seems the story of maqui is still unfolding, as much of its ethnomedicinal uses (anti-inflammatory, digestive disorders, fever and skin injuries) remain to be studied by modern science.

Commercial Uses

Maqui-derived products, such as beverages, juice concentrates, and capsules, have gained significant popularity in the food and nutraceuticals industry. Several preclinical studies have shown that anthocyanins and other polyphenols from maqui may prevent symptoms of chronic non-communicable diseases, such as obesity, cancer, cardiovascular, and neurodegenerative disorders (Céspedes *et al.* 2008; Prior and Gu 2005; Sasaki *et al.* 2007).

Initially, due to its particularly powerful antioxidant capacity and high anthocyanin content, maqui was seen as a novel superfruit, but current knowledge on maqui medicinal properties goes far beyond the antioxidant effect. Maqui's antioxidant capacity is superior to that of other common berry fruits, like acai, blueberries, strawberries, and cranberries (McDougall and Stewart 2012). The leaves of this plant have drawn attention of medical researchers, and in a recent study a nutritional supplement was prepared by micro-encapsulation of maqui leaf extracts (Vidal *et al.* 2013) The stability issue of anthocyanins is still a challenge, especially for liquid formulations. Recent studies showed lemon juice can help stabilize maqui polyphenols (Gironés-Vilaplana *et al.* 2012; 2014). The colorful anthocyanins from maqui have been used to enhance the color of red wine and for the production of organic food compatible dyes (Misle *et al.* 2011).

As metabolic syndrome is increasing worldwide, it has been suggested that anthocyanins from maqui berries could be used as a supplement to ameliorate type 2 diabetic conditions. According to a recent study, DSG, a distinctive anthocyanin of maqui berry has insulin-like properties in vivo and it can increase insulin sensitivity in muscle and liver cells (Rojo *et al.* 2012). This antidiabetic effect is seemingly potentiated by the other anthocyanins in maqui. This finding illustrates antidiabetic potential of maqui, stimulating interest for further research.

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Betalains from *Chenopodium quinoa:* Andean Natural Dyes with Industrial Uses beyond Food and Medicine

(K. Cubillos-Roble, B. L. Graf, A. Troncoso-Fonseca, J. Delatorre-Herrera, L. E. Rojo)

History and Coloristic Properties of Quinoa

Historical records indicate that the natives of South America domesticated quinoa (*Chenopodium quinoa* Willd.) over 5000 years ago (Sepúlveda *et al.* 2004). When the Native Americans settled in the Andes, quinoa was baptized with the Quechua word *Chisiya mama* or “the mother grain.” Archaeologists believe the Tiwanaku culture, the most prominent Pre-Incan civilization, based its diet on the quinoa grain (Kolata 2009), as they recognized its extraordinary nutritional traits (Lamothe *et al.* 2015). Chipaya people, one of the earliest cultures of the Andes (current Chile, Peru, and Bolivia), also attributed a magical force to the quinoa plant, as they used it in religious ceremonies like the mortuary ritual (Esatbeyoglu *et al.* 2014). In mortuary rituals, mourners prepared bags with cooked and raw quinoa for the deceased to eat during their journey through the spiritual world (Acosta Veizaga 2001).

In addition to its nutritional value (FAO 2011), quinoa is rich in betalains, a class of natural pigments found in the seeds and aerial parts of the plant (Tang *et al*. 2015)˙ In Bolivia, the Spanish word *mojuelo* is the name for a betalain-rich by-product of quinoa processing. Mojuelo is seen as a source of colorants for foodstuff and llama wool. Historical records indicate that natural colorants were common in Andean pre-Hispanic cultures, but as commonly happens in human history, the social interaction between Spanish conquerors and Andean natives resulted in the introduction of new colorants like carminic acid, beet juice, beet powder (dehydrated beets), and beta carotene and the loss of local natural pigments, like those from quinoa seeds (Cassman 1990).

Chemistry and Ethnobotany

Although betalains are typically associated with beetroots (Nemzer *et al*. 2011), these natural pigments are also present in other members of Caryophyllales, including certain varieties of quinoa. Betalains impart an attractive red-purple color to the fruits/seeds, leaves, and inflorescences of this Andean crop (Figure 5.30). The variation in betalain content in the pericarp among quinoa varieties gives the fruits/seeds their characteristic variety of colors (Figure 5.31). Betalains are water-soluble nitrogen-containing compounds derived from tyrosine. To date, 55 different chemical structures of betalains have been described. They are found in 13 plant families of the order Caryophyllales (Castellanos-Santiago and Yahia 2008), including Amaranthaceae. These natural dyes are divided into two primary subgroups (Figure 5.32A–C) that differ in their pigmenting properties: betacyanins (red-violet) and betaxanthins (yellow-orange) (Strack *et al*. 2003). Other common food sources of betacyanins and betaxanthins are Swiss chard (*Beta vulgaris* L. ssp. Cicla) and cactus fruit [*Opuntia ficus-indica* (L.) Mill.] (Tang *et al*. 2015). The best known betacyanin is betanin, which gives beets and cactus fruits their

Figure 5.30 Variety of colors of quinoa fruits and vegetative parts. © 2014 David Wu.

Figure 5.31 Variation in quinoa seed color. © 2007 Michael Hermann, http://www.cropsforthe future.org/.

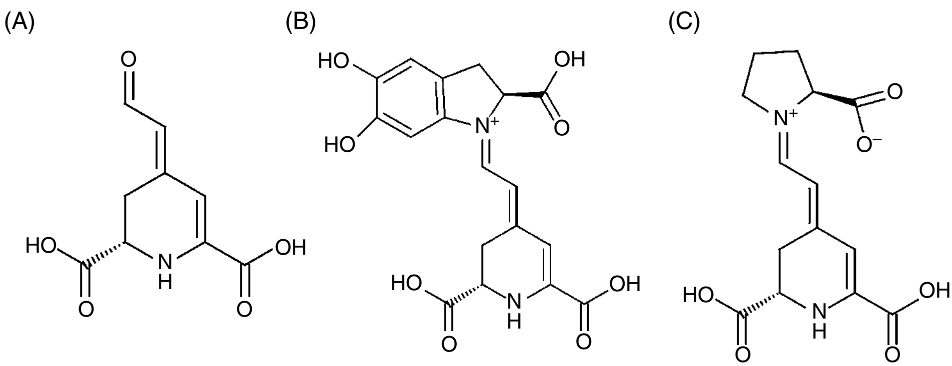

Figure 5.32 The structure scheme shows (A) betalamic acid, the chromophore and precursor of all betalains; (B) betanidin, the aglycone of most of the betacyanins; and (C) indicaxanthin, a proline-containing betaxanthin.

typical red-violet color. However, one recent study has reported betanin and isobetanin to be the most abundant betalains in three different quinoa genotypes (Tang *et al.* 2015). Due to the color of betacyanins, which absorb visible light in the range of 536–538 nm, they are often mistaken for anthocyanins, a group of polyphenols with maximum UV absorbance of 520 nm (Tang *et al.* 2015). However, betacyanins are structurally distinct from anthocyanins (Figure 5.32A–C). Betacyanins are biosynthesized from tyrosine by the condensation of betalamic acid with a dihydroxyphenylalanine (DOPA) derivative, while betaxanthins are formed from the condensation of betalamic acid with an amino acid or amino acid derivative. Betalains are normally extracted with acidified aqueous methanol (Tang *et al.* 2015) and are stable between pH 3 and 7, which makes them attractive as food colorants. Surprisingly, rigorous chemical characterization of betalains in quinoa is still lacking, as well as an understanding of genetic and environmental effects on betalain production in quinoa.

Modern Uses

Bolivia and Peru are presently the major global producers of quinoa; Bolivia is the world-leading exporter of raw quinoa and quinoa-based products (FAO 2013). It has the largest collection of ecotypes and a seed bank with over 3000 varieties of quinoa seeds. Although Chile and the United States are small producers of quinoa seeds, American and Chilean researchers are developing innovations in order to increase the value of quinoa seeds beyond the commodity prices (FAO 2011; Graf *et al.* 2014).

Colorful betalains from quinoa provide a variety of shelf-stable, bright colorants with multifaceted applications (Moreno *et al.* 2008). For example, betanin can be used for coloring dairy products such as yogurt and ice cream, as well as sauces and soups. Color is among the key features for food attractiveness. The right color in foodstuffs can increase their acceptance and market price. In fact, higher prices are not a deterrent to consumers when purchasing more healthy-looking products. Food color can positively influence the hedonic and sensory experience of food. Thus, the right combination of flavor and color can positively reinforce the intake of certain edible products. According to the regulation on food additives, betanin is permitted as a natural red food colorant (E162) in the European Union (Moreno *et al.* 2008), and as a component of beet juice by the FDA. Moreover, betanin is used as a colorant in cosmetics and pharmaceutical formulations due to the safe toxicity profile (Esatbeyoglu *et al.* 2014).

The industrial processing of quinoa seeds for food applications yields significant amounts of *mojuelo* in Perú and Bolivia (Acuña Soliz 2006) The production of mojuelo has increased dramatically due to the high and increasing international demand for quinoa, providing new opportunities for technology-based business among quinoa farmers in Chile, Peru, and Bolivia (Acuña Soliz 2006).

A number of Chilean and Peruvian quinoa varieties are particularly rich in betalains, and the stems and leaves of these quinoa varieties can be used to obtain natural dyes. The coloristic properties of quinoa betalains vary depending on the specific compound, plant organ, and method used for extraction. Currently, Peruvian women are using quinoa betalains to stain fabrics, soaps, ice cream, and modeling clay (FAO 2011).

In conclusion, the use of colorful ecotypes of *Chenopodium quinoa*, not only as a staple crop but also as a source of natural pigments with broad industrial applications, is drawing the attention of entrepreneurs, farmers, and consumers in Andean countries. Further development of betalain extraction/concentrating technologies may offer new sources of income for Andean quinoa farmers from Peru, Bolivia, Ecuador, and Chile, which along with the sustainable production of "Mother Grain" might increase profitability of quinoa in the coming years.

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