

Corn History and Culture

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PRODUCTION AND IMPORTANCE

Cereals are the most important source of food, and cereal-based food are a major source of energy for the world population (Food and Agricultural Organization, 2018). Worldwide, the three cereal crops with the greatest production are corn, rice, and wheat; among other commodities such as vegetables, roots, and tubers (Fig. 1.1). These cereals are the most relevant grains in the human diet and are one of the main sources of nutrients in developing countries because of their availability and affordability. Of these cereals, the greatest land area by far is devoted to wheat, but because of its lower average yield per unit of land area, the total production of wheat is less than that of corn or rice. Of these main cereals, wheat and rice are primarily food crops, whereas corn is primarily used as feed (see Chapter 23) and fuel bioethanol crop (see Chapter 22).

Corn (*Zea mays* L.) belongs to the grass family Poaceae (Gramineae), tribe Maydeae. Cultivated maize is a fully domesticated plant and is one of the most productive species of food-plant. It is a C₄ plant with a high rate of photosynthetic activity, a multiplication ratio of 1:600–1:1000, and the highest potential for carbohydrate production per unit area per day. Corn originated in the tropics; however, it is grown in a wide diversity of environments located from 58°N in Canada to 40°S in Argentina (Paliwal et al., 2000).

Today, corn is the most important cereal grain in terms of production. Corn became the world leader surpassing rice and wheat about 10 years ago due to the development of high-yielding regular and genetic-modified genotypes and its wider adaptation to different ecosystems. It is the top ranking cereal in grain yield per hectare. Corn has high value and economic importance worldwide not only as human food, but also as animal feed and as feedstock for a large quantity of industrial products and biofuels. In subsistence agriculture, corn is grown and used as a basic food crop, but in developed countries, with a concurrent increase in demand for wheat flour and animal-derived food, the primary use is as animal feed. As a result, in many developed countries, more than 85% of the corn produced or imported are used for animal feed (Food and Agricultural Organization, 2018).

Maize is the most extensively cultivated and consumed cereal in the world, with a production of more than 1 billion of metric tons and an area harvested of almost 200 millions of hectares in 2016. World corn production has increased due to both increased land area devoted for its production and increased yield per unit of land. In 2016, approximately 70 and 63 millions of hectares were planted with corn in America and Asia, respectively (Fig. 1.2) (Food and Agricultural Organization, 2018). The American continent produces nearly 55% of the world's total production, followed by Asia, Europe, and Oceania. The U.S. Corn Belt produces 38% of the world's total, followed by China (18%), Brazil (8%), Argentina (8%), Baltic States (9.5%), India (5%), and Mexico (3%).

Corn is consumed across the world in a variety of whole and processed products that are described in Chapters 16, 17, and 20. Corn is consumed on the cob and suitable for the development of a variety of food such as popcorn, polenta, tortillas, mush, breakfast cereals, snack food, bakery items, and cornmeal among others. Nowadays, eating habits of people all over the world have changed from eating traditional to nontraditional corn food, such as fast food, breakfast cereals, and extruded and nixtamalized snacks. The refined cornstarch is transformed into an array of syrups and sweeteners that are strongly competing with the traditional crystallized sugar refined from sugarcane or beet (Serna-Saldivar, 2010a). Direct corn consumption is concentrated in America and Africa. Particularly in Mexico, the per capita food supply (included protein) for maize is higher than that for the rest of America and superior than the values for the world and the five continents. Mexico is one of the ten major consumers of maize with a per capita consumption of 34 kg/year (Fig. 1.3) (Food and Agricultural Organization, 2018).

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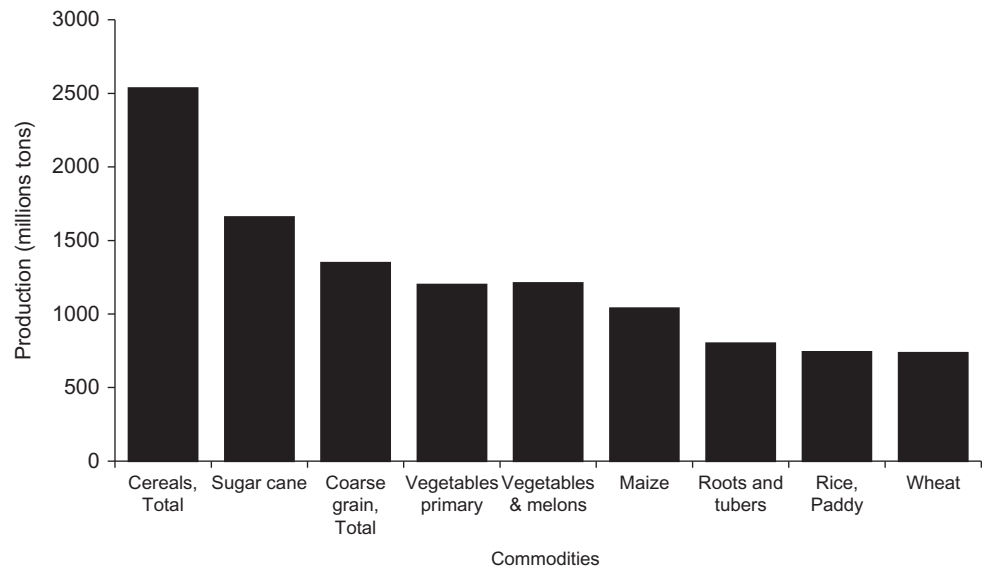


FIG. 1.1 Most produced commodities in the world, 2016. (Source: Food and Agricultural Organization, 2018. FAOSTAT, FAO Statistical Databases. Available from: <http://apps.fao.org/> (2 February 2018).)

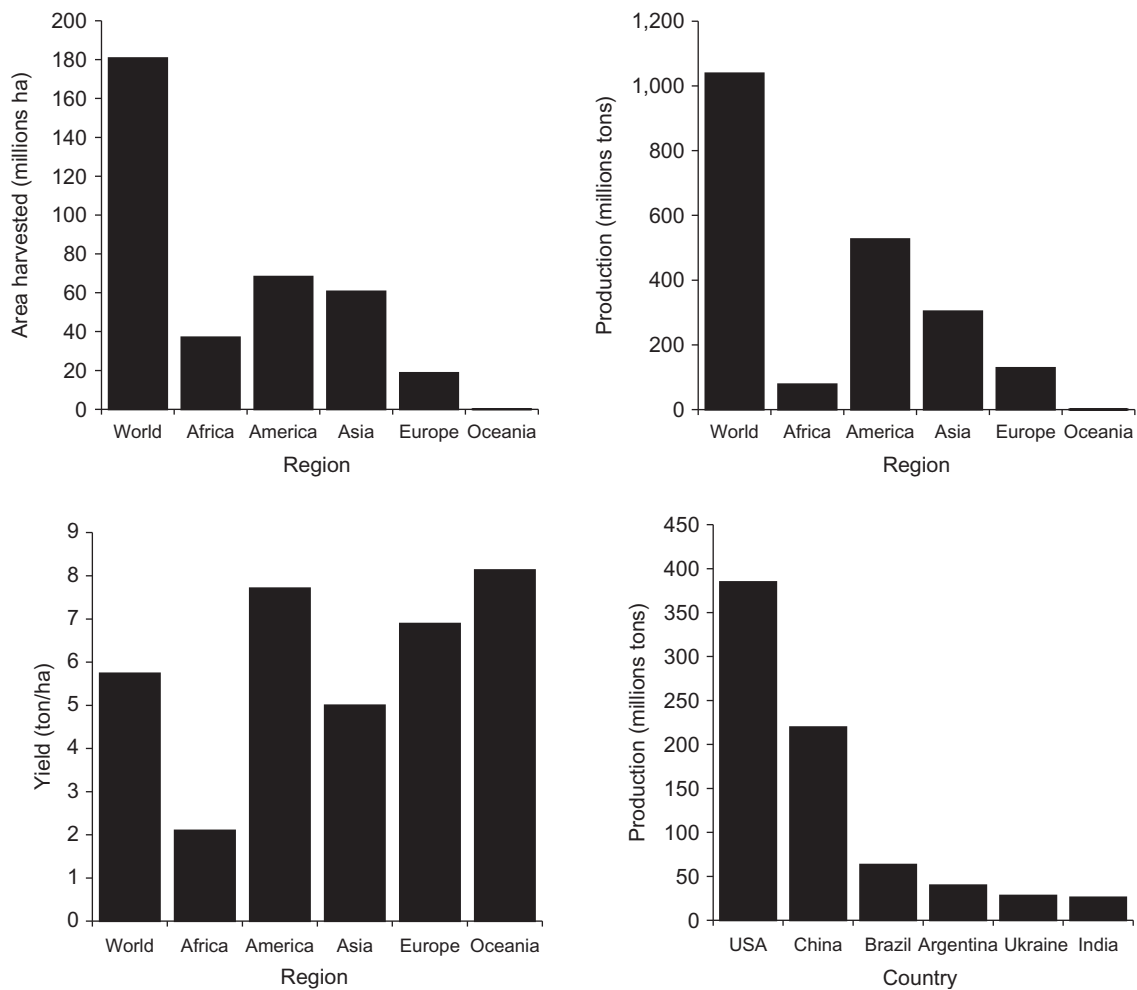


FIG. 1.2 Worldwide corn production. (A) Maize area harvested by region, (B) maize production by region, (C) maize yield by region, and (D) Top 6 maize producers. (Source: Food and Agricultural Organization, 2018. FAOSTAT, FAO Statistical Databases. Available from: <http://apps.fao.org/> (2 February 2018).)

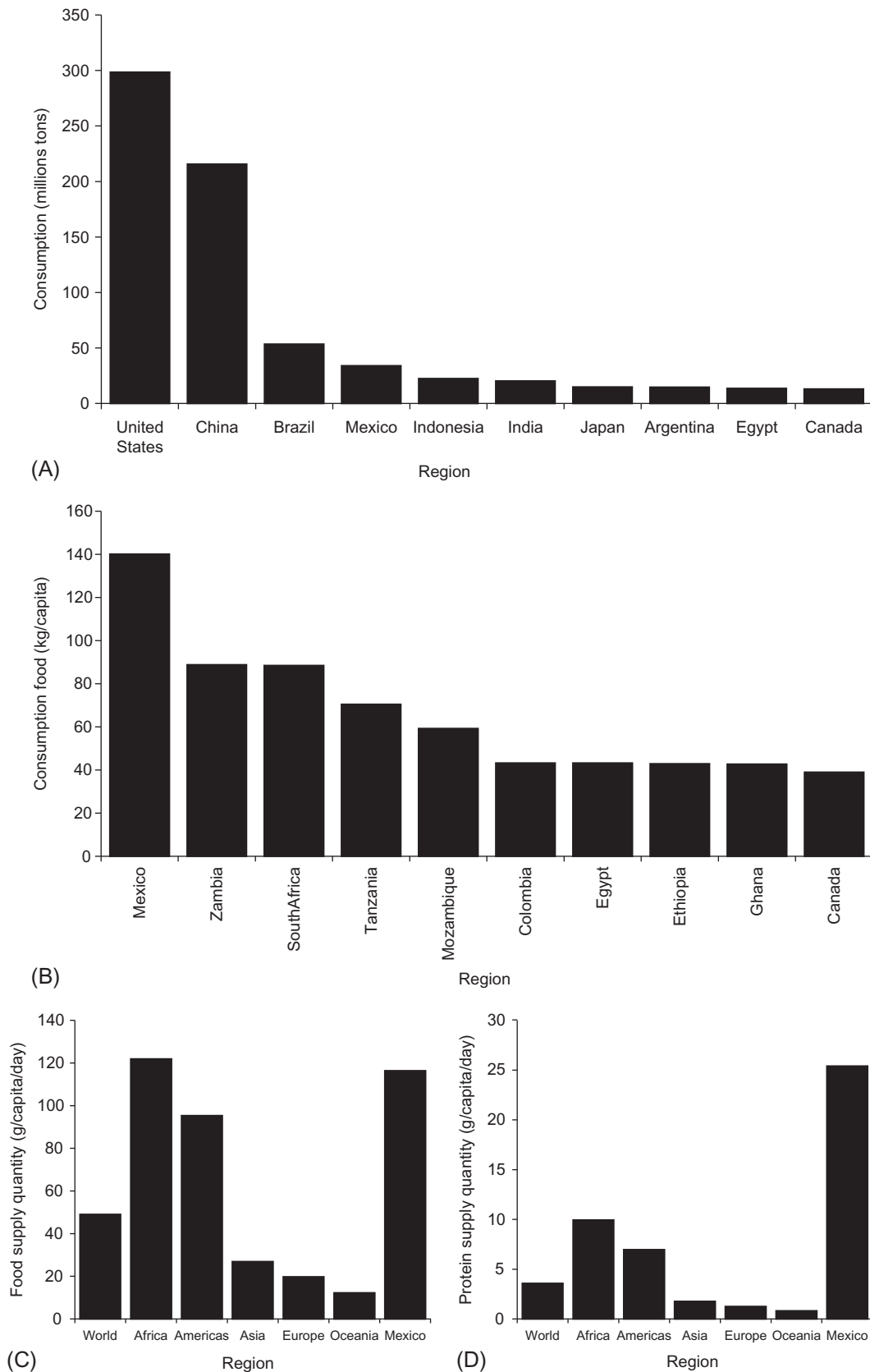


FIG. 1.3 Maize consumption worldwide. (A) Top 10 maize consumers based on average values from 2013 to 2015. (B) Top 10 maize consumers per capita based on average values from 2013 to 2015. (C) Per capita supply of maize available for human consumption as food and protein supply. (Source: Food and Agricultural Organization, 2018. FAOSTAT, FAO Statistical Databases. Available from: <http://apps.fao.org/> (2 February 2018).)

Corn has a high yield potential in many environments. Very few crops average more than 3.5 metric tons per hectare (t/ha) on a worldwide basis; potatoes, corn, and rice are the primary exceptions. Not all corn-producing areas have corn yields that exceed 3.5 t/ha. In fact, the United States, Canada, China, Europe and the Baltic States, Argentina, and Oceania are the only areas to significantly yield more than this amount.

CORN HISTORY AND CULTURE

Origin and Evolution

Corn was originated in the highlands of Mexico between 7000 and 10,000 years ago. Archeological data has shown that corn was cultivated in the year 2000–2500 BCE. The oldest paleoetnobotanic evidence of its domestication is in an archeological site named “Nac Neish,” located in the southern part of the state of Tamaulipas, Mexico. It consists of three primitive caves presenting data between 6000 and 20,000 years BC. Other important archeological sites were located in the states of Puebla, Oaxaca, and Mexico. The oldest record for corn and teosinte (*Zea mexicana* and *Zea perennis*) dated 5000 years BC was found in the archeological sites named “La Playa” and “Nevada,” located in the Tehuacan valley. Two types of teosintles named Chalco and Balsas were found in western Mexico located at high and low altitudes, respectively.

Three theories about the evolutive origin of corn have been postulated. The first one proposed that maize is the result of crossing teosinte by *Tripsacum*. The second is that it comes from a tunicated maize and that teosintle is the result of crossing *Zea* by *Tripsacum*. The third, and most recognized, is that corn evolved from teosinte (Table 1.1) (Galinat, 1988; Cuevas-Sánchez, 2011; Serna-Saldivar, 2015). Mangelsdorf (1986) believed that corn evolved from extinct popping corns that contained glumes covering each kernel. Wilkes (1972) found that teosinte and *Tripsacum* could not cross in nature, nor in laboratory conditions, and the structure of the pollen of these two genus also confirmed that teosinte did not derive from their hybridation. In addition, Paulis and Wall (1977) determined that electrophoretic patterns of zeins and alcohol-soluble reduced glutelins of teosintes were similar to corn, but those of *Tripsacum* showed marked differences. Then, the most accepted theory of the origin of corn is that teosintle is the ancestor because (1) the free and frequent hybridation of teosintle and corn occurring in nature, (2) the same number of chromosomes ($n = 10$) with an identical structure in both species, and (3) cultivars share several anatomical features including similar morphological pollen characteristics.

According to Galinat (1988), the origin of corn occurred during the invention of the new world agriculture. The American Indians developed corn and were the first breeders because they transformed the tiny two-rowed ear of teosinte of about 3 cm long into the first tiny corn ear with its four ranks of paired female spikelets. This transformation likely took between 100 and 200 years. Evidence based on chromosomal studies and cob morphology indicates that at least two independent domestications from two teosintes gave origin to two different corns (classified as pyramidal or cylindrical corns). The pyramidal such as Palomero Toluqueño, Conico, and Chalqueño are distant descendants from Chalco Teosinte

TABLE 1.1 Teozintle Diversity in Mexico		
Group	Cycle of Life	Specie (Location)
Luxurians	Annual	<i>Zea luxurians</i> <i>Zea nicaraguensis</i> <i>Zea</i> sp. (Oaxaca)
	Perenne	<i>Zea perennis</i> (Jalisco, Colima) <i>Zea diploperennis</i> (Jalisco) <i>Zea</i> sp. (Nayarit, Michoacan)
Zea	Annual	<i>Zea mays</i> spp. <i>huehuetenanguensis</i> <i>Zea mays</i> spp. <i>mexicana</i> Races: Nobogame (Chihuahua) Durango (Durango) Mesa Central (Guanajuato, Jalisco, Michoacan) Chalco (Estado de Mexico, Puebla, Tlaxcala) <i>Zea mays</i> spp. <i>parviglumis</i> (Nayarit, Jalisco, Michoacán, Guerrero, Oaxaca)
Source: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2011. Recopilación, generación, actualización y análisis de información acerca de la diversidad genética de maíces y sus parientes silvestres en México. CONABIO. México. Available from: http://www.biodiversidad.gob.mx/genes/proyectoMaices.html (23 September 2017).		

(*Z. mexicana*) which still grows wild from Chihuahua (Mexico) to Guatemala. The cylindrical corns are most prevalent in modern corn and represent another group of races tracing back to Guerrero or Balsas Teosinte (*Zea parviglumis*). The oldest remains of 8-rowed corn from Tehuacan, Mexico, are 7200 years old. The 12-rowed ear of Chapalote with a higher cob diameter is about 3000 years old (Table 1.1). Apparently, the large kernalled eight-rowed maize (*Cacahuacintle* or Cuzco) arose independently from Balsas Teosinte about 2500 years ago. Parallely, the Palomero Toluqueño indigenous Mexican race, characterized by elongated flint kernels that evolved from Chalco Teosinte, originated the 16-rowed Pepitilla corn. The cross of *Cacahuacintle* from Balsas and Pepitilla from Chalco teosintes originated the high-yielding 14-rowed dent corns generally planted in the Corn Belt today. The recurrent selection by many generations of humans has resulted in a magnificent kernel-bearing structure capable of carrying a high number of broad caryopses that would not shatter from the dry cob. The 10-chromosome races encoded precious genetic information that made corn the most adapted and productive crop in the world (Galinat, 1988).

Historical Perspective

Corn is also known by various common names, being the most widely used maize. In Spanish, it is called “maiz,” in French “mais,” in Portuguese “milho,” and in India “makka.” Wellhausen et al. (1951) classified several races of corn; one group denominated “indigenous or ancient” dated at least 5000 years old that included: Nal Tel, Chapalote, Palomero Toluqueño, and Conico or Arrocillo amarillo. These produce small ears with vitreous kernels that are able to pop or revert. A second group of four distinctive races called “exotic precolombian” was probably introduced to Mexico from Central and/or South America: *Cacahuacintle*, 8 rowed floury, oloton, and sweet corn. *Cacahuacintle* is characterized for producing large and floury kernels on a large ear. The *cacahuacintle* name derives from the Nahuatl *cacahuacentli*, meaning (*centli*) kernels that look alike cocoa beans (*cacahuatl*) (Table 1.2).

Today in Latin America, there are recognized 220 races of corn, from which 64 races are associated to Mexico (Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2011). Races of corn are a group of racial complexes which are associated to a defined climatic and geographic region. There are seven racial complexes defined as “Conicos,” “Sierra de Chihuahua,” “Ocho Hileras,” “Chapalote,” “Tropicales Precoces,” “Dentados Tropicales,” and “Maduración

TABLE 1.2 Races of Corn in Mexico

Indigenous or Ancient	Exotic or Pre-Columbian	Mestizas Prehistoric	Moderns Incipient	Not Defined
Palomero Toluqueño	Cacahuacintle	Cónico	Chalqueño	Conejo
Arrocillo Amarillo	Harinoso de Ocho	Reventador	Celaya	Mushito
Chapalote	Olotón	Tabloncillo	Cónico Norteño	Complejo Serrano de Jalisco
Nal-Tel	Maíz Dulce	Tehua	Bolita	Zamorano Amarillo
		Tepecintle		Blando de Sonora
		Comiteco		Onaveño
		Jala		Dulcillo del Noroeste
		Zapalote Chico		
		Zapalote Grande		
		Pepitilla		
		Olotillo		
		Tuxpeño		
		Vandeño		

Source: Wellhausen, E.J., Roberts, L.M., Hernández, X.E., Mangelsdorf, P.C., 1951. Razas de maíz en México. Su origen, características y distribución. Oficina de Estudios Especiales-Secretaría de Agricultura y Ganadería, Folleto técnico No. 55, México.

TABLE 1.3 Groups of Racial Complex of Corn

Complex	Races
Conicos	Arrocillo, Cacahuacintle, Cónico, Cónico Norteño, Chalqueño, Dulce, Elotes Cónicos, Mixteco, Mushito, Mushito de Michoacán, Negrito, Palomero de Jalisco, Palomero Toluqueño, and Uruapeño
Sierra de Chihuahua	Cristalino de Chihuahua, Gordo, Azul, Apachito, Complejo Serrano de Jalisco. Mountain Yellow
Ocho Hileras	Blando de Sonora, Onaveño, Harinoso de Ocho, Tabloncillo, Tabloncillo Perla, Bofo, Elotes Occidentales, Tablilla de Ocho, Jala, Zamorano Amarillo, Ancho, and Bolita
Chapalote	Chapalote, Reventador, Dulcillo del Noroeste, and Elotero de Sinaloa
Tropicales Precoces	Nal-Tel, Zapalote Chico, Conejo, and Ratón
Dentados Tropicales	Tuxpeño, Vandeño, Tuxpeño Norteño, Tepecintle, Zapalote Grande y Celaya, Pepitilla, Nal-Tel, Choapaneco, Chiquito, and cubano amarillo
Maduración tardía	Olotillo, Dzit-Bacal, Comiteco, Motozinteco, Tehua, Olotón, Coscomatepec, Dzit Bacal, Negro de Chimaltenango, Quicheño, and Serrano

Source: Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2011. Recopilación, generación, actualización y análisis de información acerca de la diversidad genética de maíces y sus parientes silvestres en México. CONABIO. México. Available from: <http://www.biodiversidad.gob.mx/genes/proyectoMaices.html> (23 September 2017).

tardía” or late maturing (Vielle-Calzada and Padilla, 2009; Comisión Nacional para el Conocimiento y Uso de la Biodiversidad, 2011; Sánchez, 2011). Each complex is represented by several local races distributed along Mexico and Latin America (Table 1.3).

These races crossed with the ancient corn germplasm and produced the base of the races widely used to breed high-yielding varieties and hybrids. In 1963, researchers at Purdue University stumbled across a naturally occurring corn mutant that contained about twice as much lysine and tryptophan than their regular counterparts (Mertz et al., 1964). The opaque-2 corn was rapidly transformed into varieties and planted throughout the world. Unfortunately, opaque-2 failed because of low yields and lack of resistance to pests. Researchers from International Maize and Wheat Improvement Center (CIMMYT) eventually developed improved forms, now named quality protein maize (QPM). Yellow and white QPM open-pollinated varieties and hybrids are being tested around the globe. In some countries such as South Africa, Brazil, China, Ghana, and Mexico, it is also being commercially grown.

Corn was so important for the Mesoamerican cultures that they have named it differently: The mayans called it *ixim*, whereas the Aztecs denominated corn on the cob *centli* and kernels *tlaolli*. *Tlaolli* had many different varieties, distinguished by the color size and texture of the grains filling the cobs. White kernels were called *iztactlolli*, black (blue or purple) *yahuatl*, yellow *xiuhtocatlulli*, stained *xuchicentlaulli*, mixed colored *cuappachcentlulli*, and the early maturing *tepil* (Serna-Saldivar, 2015).

After the American continent was discovered, the corn crop eventually adapted to Spain and from there it was distributed to other parts of Europe. Corn was mainly planted on farmlands close to Portugal and soon disseminated to the neighboring country. During the middle of the XVI century, corn was established in Angola and it reached France, Italy, and Turkey until the middle of the XVIII century. From this last country, it rapidly spread to east Africa and all the way south to Madagascar. The Spaniards catalyzed the Asian connection because they traded goods from Acapulco, Mexico, to Manila, Philippines. This occurred as early as 1565, but corn became important in Asia after the XVII century (Serna-Saldivar, 2015). Today, corn is the most important cereal and productive crop in the world. The success is due to its adaptation to different ecosystems from coasts to mountains and the development of highly producing regular and biotechnological hybrids capable of yielding under commercial conditions up to 16 tons/Ha. Corn is a crop with a remarkable genetic variability; therefore, many specialty genotypes are available (see Chapter 10). The main specialty types are popcorn, waxy, high-amylose or amylo maize, sweet, blue, Cuzco, high-oil, and quality protein (QPM) (Hallauer, 2000).

GROWTH AND DEVELOPMENT

Corn is classified based on the altitude and the environment in which it is grown into two main types: tropical corn and temperate corn. Tropical corn is grown in warmer conditions located between the equator and 30°N and 30°S, while

temperate corn is grown in cooler climates beyond 34°N and 34°S. An intermediate environment known as a subtropical considers corn grown between 30° and 34° latitudes (Dowswell et al., 1996).

Normal corn plants grow and develop from a seed to a mature plant in a few months. Plant size, length of growth period, and yield potential vary importantly, depending on the production region. The corn plant is a tall leafy structure with a fibrous root system, supporting a single shoot with many leaves and one lateral branch terminated by a female inflorescence, which develops into an ear covered by husk leaves. In the upper part of the plant develops the male inflorescence known as tassel. Among commercial cereals, corn is the only one that has the male and female flowers separated. After pollination, the kernel or fruit, botanically named caryopsis, develops. The corn kernel consists of three major structures: pericarp, endosperm, and germ. The pericarp or fruit coat is a thin outer layer that protects the true seed consisting of germ and endosperm considered the first and second reserve tissues. The germ contains the embryonic axis and the scutellum, whereas the endosperm consists mainly of starch granules, which serves as the major energy source for the germination of the seed and small seedling and gluten proteins (Paliwal et al., 2000; Serna-Saldivar, 2010b). The structure, development, and description of these anatomical parts are described in Chapter 6.

Germination

Under optimal conditions of temperature and humidity, corn seeds germinate between 6 and 15 days after planting. The real time varies significantly, depending on type, temperature, and moisture of the soil. The phytohormone gibberellin plays an important role in the physiology of germination because it promotes the synthesis of lipases, phytases, several cell wall degrading enzymes, endo and exoproteases, and α and β -amylases needed to generate the necessary energy and nutrients for germination (Serna-Saldivar, 2010b). The first structure to break through seed coat is the radicle, followed by the coleoptile (protective sheath covering the emerging shoot), and then the seminal roots. The growth and elongation of the coleoptile origin the plant that emerges from the soil. The elongation of the mesocotyl stops when the coleoptile reaches light, giving a place for splitting of the coleoptile tip and the emergence of first true leaf (Fig. 1.4).

Vegetative Development

The vegetative development of the new plant continues with the growth of the seminal root system, which emanated from the seed, and continues with the nodal root system. The function of the seminal roots is primarily water absorption for the first weeks of life of the new plant. All nutrients that the young plant needs emanate from the endosperm, which stored food reserves during seed development. Additional nodal roots are developed and root system achieves its greatest depth at the

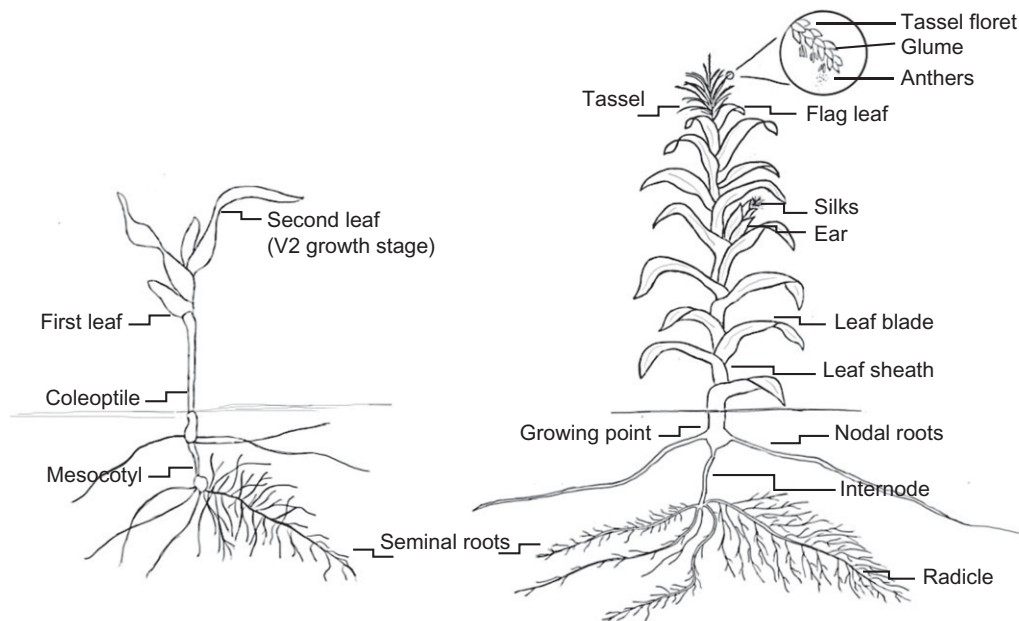


FIG. 1.4 Corn seedling plant and mature corn plant. (Source: Based on Benson, G.O., Reetz, H.F., 1984. *Corn Plant Growth-From Seed to Seedling*. National Corn Handbook, Purdue Univ. Coop. Ext. Serv., West Lafayette, pp. 1–240.)

middle of the reproductive stage (approximately 3 months after emergence). Roots and new leaves develop from the apical meristem (growing point). As other organs in the plants, rooting depth varies greatly because of genotype and environment, but depths of 1–2 m are considered in a normal range (Benson and Reetz, 1984). All corn plants have the same development pattern. A corn develops in its lifetime close to 30 leaves, produces silk after around 2 months, and reaches physiological maturity after 3 months. Under optimal conditions and depending on the specific agroecology, a new leaf emerges every 3–4 days until the tassel emerges, indicating that the plant has achieved full height. Growth during the latter part of the vegetative stage shows very rapid leaf-area formation and reproductive development (Fig. 1.4). It is important to mention that the time between growth stages varies with plant maturity, planting date, location, and number of daylight hours or photoperiod. (Ritchie and Hanway, 1997). A brief field guide for the identification of production problems in tropical and temperate corns throughout the vegetative development is presented by Lafitte (1994) and Troyer (2001), respectively.

Pollination and Kernel Development

Corn is a monoecious plant, which means that staminate flowers are the tassel and the pistillate flowers are the ear shoots. This separation of male and female parts allows auto and cross pollination and is the key to the improvement of corn by maize breeders and geneticists. The emergence of the tassel from the whorl and of silks from the ear shoots indicates the beginning of the reproductive phase of the plant development. Anthers are in the individual stamens and at the anthesis time (period during which a flower is fully open and functional); anthers are expelled and the pollen escapes. The tassel is capable of producing between 2 and 5 million pollen grains per plant. In contrast, in the ear, each potential kernel (ovule) produces a fiber called a silk which is an elongation of the style, attached to an individual ovary. An ear may produce between 600 and 1000 silks. Pollen shed by tassels fall on these silks (Fig. 1.4). A single pollen grain germinates on each silk and produces a pollen tube that grows down the silk until the ovary is fertilized (Hoeft et al., 2000). Chapter 6 provides details of this process.

The main function of the plant, after fertilization, is to develop the corn ears. Ear development or postsilking stages are identified as blister, milk, dough, dent, and physiological maturity. In general, it takes approximately up to 65 days to pass from silking to physiological maturity. Physiological maturity is reached when the kernels on the ear have reached maximum dry matter accumulation and an excellent visual indicator is known as a “black layer” or hilum (a dark closing layer develops between the basal endosperm and the vascular area in the pedicel) as well as the kernel “milk line” (a boundary between the solid and liquid phases of the maturing endosperm and visible on the side opposite to the germ). This line moves gradually from the crown to the tip of a kernel as maturity approaches. Milk line helps to estimate the time to maturity, whereas the black layer indicates strictly presence or absence of maturity (Farnham et al., 2003).

CULTURE AND MANAGEMENT

Climatic Requirements

Climate is fundamental in determining major production regions for corn cultivation. Although corn is grown over a wide range of agroclimatic conditions, specific weather factors greatly influence the production potential. In this sense, many management practices are determined by climate variability. Temperature and moisture are the key factors that determine if corn is adapted to a target area, but growing-season length and solar radiation are also limiting factors.

Firstly, growing season is defined as the part of the year during which local weather conditions permit normal plant growth. Growing season varies over diverse areas of the world (from Northern hemisphere to tropical area, and southern hemisphere). In most regions of the world, the “rainy seasons” set limits to the length of the growing season.

Secondly, temperature and moisture interact and influence directly the developmental aspects, and thus the physiological processes. For corn, Sanchez et al. (2014) defined temperature thresholds for the key physiological processes such as leaf initiation, shoot growth and root growth, and for the most susceptible phenological phases such as sowing to emergence, anthesis, and grain filling (Table 1.4). Corn responses to temperature in different ways to phenological phases and development stages. Temperature influences corn germination and emergence. For example, radicle and shoot elongation is better at about 30°C and almost nonexistent below 9°C and above 40°C. The influence of temperature for later vegetative stages is similar to that of early stages. The fastest rate of development is reached at temperatures of 21°C (daily minimum) and 32°C (daily maximum). However, during the reproductive stages, development is less temperature-sensitive compared to the vegetative stages. There is a curvilinear relationship between temperature (15–30°C) and the time from emergence to tassel initiation. Optimum temperatures to obtain maximum grain yields may not be optimum for accelerated

TABLE 1.4 Summary of Differential Temperatures for Relevant Processes and Development Phases in Corn^a

Processes	Mean Temperature (°C)			n
	T _{min}	T _{opt}	T _{max}	
Developmental phases				
Lethal	−1.8±1.9	—	46.0±2.9	14
Leaf Initiation	7.3±3.0	31.1±1.7	41.3±1.9	24
Shoot growth	10.9±1.5	31.1±0.8	38.9±2.8	10
Root growth	12.6±1.5	26.3±1.8	40.1±3.6	11
Phenological phases				
Sowing to emergence	10.0±2.2	29.3±2.5	40.2±2.1	7
Sowing to tassel initiation	9.3±2.7	28.3±3.8	39.2±0.6	27
Anthesis	7.7±0.5	30.5±2.5	37.3±1.3	10
Grain filling	8.0±2.0	26.4±2.1	36.0±1.4	11
Whole plant	6.2±1.1	30.8±1.6	42.0±3.3	29

^aTemperatures: $T_{\min}$, base; T_{opt} , optimum; $T_{\max}$, maximum; n, number of literature sources (modified from Sanchez et al. (2014)).

corn development. Maximum corn yields are related with maximum daytime temperatures (24–30°C) (Hoeft et al., 2000). Cool nights and sunny days with moderate temperatures are considered ideal. High-temperature stress during the pollination period can result in poor kernel establishment.

The third factor is moisture, which is associated with soil water availability. Moisture accessibility to the corn plant contemplates the quantity of moisture in the soil, the soil texture, and the atmospheric demand for water. Atmospheric demand for water is a function of temperature, solar radiation, wind, and humidity of the air. The magnitude of plant stress depends on the relationship between soil moisture availability and atmospheric demand. In fact, stress occurs when evapotranspiration drops below potential transpiration. Based on that, the dimensions of yield loss vary depending on evapotranspiration, crop stage, and soil fertility. In most relevant corn-growing areas, a shortage of water, especially at critical stages of the growing cycle, is often a serious yield-limiting factor (Ribaut et al., 2009).

The amount of moisture in the soil is also relevant. For example, optimal soils store more than 5 cm of plant-available moisture per 30 cm of soil depth, and during periods of peak demand, water use may exceed the amount of precipitation that is received. Water use by corn depends on crop stage and this period also coincides with flowering and pollination. Therefore, to reduce the potential stress, subsoil moisture reserves are crucial. However, excess of moisture also reduces corn yields where plants under flooding are damaged or killed; nevertheless, the main diminutions are due to saturated soil conditions (Farnham et al., 2003). Dowsell et al. (1996) describe the main corn-growing environments in more detail, indicating the mean, minimum, maximum, and optimal temperatures and moisture in a given season.

Soil Management

Corn is grown in a multiple-cropping system. Such systems involve growing two or more crops on the same field in a year. Sequential cropping (growing one crop after another in the same year) and intercropping are types of multiple cropping and include numerous different systems. Sequential systems are most common where the growing season is long, and intercropping systems are most popular where labor is readily available and inexpensive. Various forms of multiple cropping include corn, especially in more tropical areas. Some of the more common crops grown in rotation with corn are oats, wheat, barley, soybean, sorghum, alfalfa, and numerous clovers and grasses (Farnham et al., 2003; Brummer, 2006).

The greatest negative consequence of cropping systems involving mainly row crops is soil erosion. A term denominated soil-loss tolerance is defined as the maximum amount of soil erosion that will permit a high level of productivity to be sustained both indefinitely and economically. Then the excessive cultivation of soils that are row-cropped can create problems with soil structure. Techniques for conserving soil are numerous and include cover crops, strip cropping, contour strip cropping, wind breaks, grass waterways, terracing, choice of crops grown, and conservation tillage. It is important to

understand that the main components of the soil environment include structure, texture, temperature, moisture, air, and nutrient availability and all of them need to be considered to maintain a proper soil structure (Carter, 1994).

Rotations with forage legumes allow the equilibrium at a higher level of soil organic matter compared with nonleguminous row crops. Where corn yields are high and the crop residues are returned to the soil, the level of organic matter is also high. Cropping and tillage systems have major impacts on potential soil erosion. Less row cropping, delayed tillage, and greater crop residues on the soil surface all serve to reduce potential soil losses.

Erosion can be reduced with the use of conservation tillage. Tillage includes benefits in terms of its soil-loosening, seedbed-preparation, and weed-control effects. The objective of a tillage system is to provide a good seedbed, help control weeds, and modify the soil environment to make it as favorable as possible for corn growth while minimizing soil erosion. There are two main types of tillage, conventional and conservation. Conventional tillage includes the most common and is based on a moldboard plow, chisel plow, disk plow, rotary tiller, or large disk harrow for primary tillage. Primary tillage generally would be followed by various operations involving the disk harrow, field cultivator, spring-tooth harrow, and spike-tooth harrow to further prepare the soil for planting (secondary tillage). In contrast, conservation tillage is related with any system that reduces loss of soil or water (Manning and Fenster, 1983). Such systems emphasize leaving varying amounts of crop residue on the soil surface. Conservation tillage has many forms, ranging from those in which only a small slit is opened in the soil ahead of the planter unit to full-width tillage that could even involve a modified moldboard plow. However, any definition of conservation tillage depends on what is considered to be conventional tillage for a given area (Carter, 1994). One of the major reasons conservation tillage methods are becoming so popular is that they allow increased intensity of row crop production, while keeping soil loss below established tolerance levels on soils where this would be impossible with conventional tillage methods. A recent review by Abdalla et al. (2013) showed that the adoption of conservation tillage practices reduced carbon dioxide emissions, while also contributed to increases in soil organic carbon and improvements in soil structure with a number of other advantages that justify its wider adoption.

Water and Nutrient Management

Main crop management practices include proper irrigation and plant nutrition. The major factors affecting water availability is how much water the soil can store per unit of depth and to what depth the subsoil is favorable for water storage and root growth. It is important to remember that part of the rainfall is lost to runoff, drainage, and evaporation. Soil storage capability determines how much moisture can be in reserve to supplement crop-season rainfall. Strategies to decrease evaporation and runoff and to increase infiltration and storage capacity are desirable. In tillage systems, less water runs off. Excess water can be a problem with fine-textured soils to the extent that drainage becomes an important management input. Irrigation may also require certain drainage needs. Random systems are used to drain scattered wet spots, whereas regular systems feature uniformly spaced equipment to drain an entire area. Ditches are the main method of surface drainage, whereas tiles are the main method used in subsurface systems (Farnham et al., 2003).

In term of essential nutrients for plant nutrition, it is necessary to recognize which ones are most likely to limit production. Essential elements are defined as those which plants acquire from the air and water like carbon (C), oxygen (O), and hydrogen (H). The other elements come from the soil. The six that are used in the greatest quantities are nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S). These elements are referred to as macronutrients and are sometimes further subdivided into primary (N, P, and K) and secondary (Ca, Mg, and S). The nutrients iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), boron (B), molybdenum (Mo), and chlorine (Cl) are required by plants in very small amounts and are called micronutrients, or sometimes trace or minor elements (Pingali, 2001).

Nevertheless, soils vary in the availability of the various essential elements. A key practice is to identify which nutrients are needed and numerous laboratory soil tests exist, but correlation studies must be conducted to see how well the soil tests relate to actual nutrient availability to plants. Some tests for P, K, and lime requirements and bioavailability are quite good, but for most other nutrients, the reliability ranges from fair to poor (Hoeft et al., 2000). Plant analyses can also be useful in determining nutrient deficiencies; however, they are often not useful for correcting the problem in the year they are taken. The two most distinctive deficiency symptoms on corn are those for N and K. Severe N deficiency early in the growing season is typified by spindly pale green to yellow plants. As plants get larger, the lower leaves show a V-shaped yellowing from the leaf tips down the midrib, with the leaf margins remaining green the longest. This response is in contrast to K deficiency, in which yellowing and then dying of lower leaf margins occurs, leaving the midrib green.

Fertilizer usage in the world has shown a tremendous increase since the green revolution. The principal factors affecting total commercial fertilizer use include cropland area, fertilizer price, commodity price and programs, soil characteristics, climate and weather conditions, and other practices such as crop rotation and nutrient applied technology. Nitrogen, P, K, and sometimes S are applied as fertilizers to the soil as manure and/or commercial fertilizers. Calcium and Mg are supplied

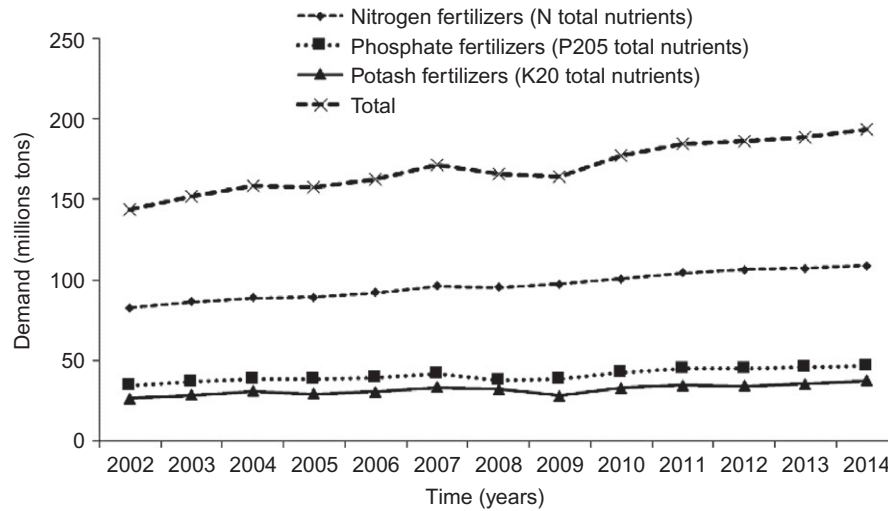


FIG. 1.5 Fertilizers consumption worldwide. (Source: Food and Agricultural Organization, 2018. FAOSTAT, FAO Statistical Databases. Available from: <http://apps.fao.org/> (2 February 2018).)

as part of liming programs. Global fertilizer usage in 2018 is estimated to be more than 200 million tons, 25% higher than the amount recorded in 2008 (Fig. 1.5). Fertilizer use varies widely by geography, with sub-Saharan Africa posting robust demand for N and K. Asia as a whole is the largest consumer of fertilizer worldwide and relies on imports of all three major nutrients. Europe also offers a surplus of all three nutrients due to large positive balances in East Europe and Central Asia. Latin America and the Caribbean depend on imports of all three main nutrients. In 2018, it is predicted that Africa will demand 4.1 million tons, Europe 15.7 million tons, the Americas 23.5 million tons, and Asia 74.2 million tons (Food and Agricultural Organization, 2018).

Pest Management

Under the concept of integrated pest management, pest control has the goal to achieve a crop production system in a way that optimizes the use of natural resources, protecting the environment and maximizing the output in a sustainable system. Control of pests assumes an important position, especially in developing countries where insect and disease pressures tend to be severe due to the subtropical and tropical climates found in these zones. Recently, pest control strategies emphasize the reduction and/or use of selective pesticides and include the use of natural, cultural, and biotechnological controls. Natural control involves the reduction of insect pest populations by the use of natural enemies, while cultural control consists of the deliberate alteration of the production system to reduce pest populations or avoid pest injury to crops. Conversely, biotechnology control includes the use of modified plants with a specific gene that imparts resistance against a particular pest, such as *Bt* genes, which controls the expression of the Bt toxin effective against lepidoptera (García-Lara and Serna-Saldivar, 2016).

In terms of chemical control, there are four types of chemical insecticides which protect against insect infestations: organophosphate, carbamates, organochlorine, and pyrethroid. Organophosphate and carbamate insecticides affect the insect nervous system by disrupting the enzyme that regulates acetylcholine, a neurotransmitter. These insecticides are not persistent in the environment. Parathyroids were developed as a synthetic version of the naturally occurring pesticide pyrethrin, which is found in chrysanthemums. Pyrethrin is the most popular botanical insecticide that acts by contact as a poison. Pyrethrins such as permethrin and bioresmethrin are popular insecticides due to its low toxicity to mammals and safe use. Pyrethrins are fast-acting insecticides and are particularly effective against adult insects. Insecticides have several advantages over fumigants: their effect is long lasting, they are easier to apply, are less dangerous, and can be applied both as preventive agents or to kill established insect populations (García-Lara and Serna-Saldivar, 2016).

There are other naturally occurring botanical insecticides which are available as an alternative to chemical control. More than 3500 compounds in approximately 400 plant families have been described to have toxic insect effects. Some botanical insecticides are not as efficient as synthetic ones, but they are similar in toxicity to humans. Citrus oils (limonene, linalool) which are extracted from citrus peels have been combined with soaps as contact poisons against aphids and mites. Nicotine derived from tobacco is a fast-acting contact killer for soft-bodied insects. Rotenone is derived from the roots of over 68 plant species. It is toxic to animals because direct contact may cause skin and mucous membrane irritation. It has a

broad spectrum poison mainly used to control leaf-eating caterpillars and beetles. Neem (*Azadirachta indica*) extracts are derived from the tropical neem tree and are effective for the control of over 200 types of insects, mites, and nematodes. The solution is effective for only 8 h after mixing and has a low toxicity to mammals. Neem is most effective under humid conditions or when the insect and plants are damp.

The use of beneficial insects, pheromones, and growth regulators has been studied as a possible alternative for biological insect control. Among the most promising biological control techniques are the use of predators and the release of sterile insects. Sterile insects treated with mutating agents can considerably lower grain infestations, especially when insects belong to the Lepidoptera order. The main disadvantage of the use of beneficial insects is that they leave behind body casts, exoskeletons, and other insect residues. Pheromones are chemical agents secreted by insects as sexual attractors. These chemicals are used to attract insects and predict populations. Pheromone traps are used to catch insects especially when the number of insects infesting is low, giving the opportunity to detect and control insect populations before they cause economic damage. The use of pheromones when insect populations are reduced also lowers their reproduction rate because these chemicals confuse insects. The use of growth agents and hormones that are essential for metamorphosis has potential in insect control programs, since these chemical compounds inhibit important physiological processes and have low toxicity for mammals (García-Lara and Serna-Saldivar, 2016).

Biotechnology has become a prominent player in pest management. Genetically engineered crops are capable of resisting insect and disease infestations as well as of exhibiting resistance to particular herbicides. Through the use of genetic engineering, scientists have been able to select a desirable gene from one species and insert it into another, resulting in a highly specific variety that expresses highly desirable attributes. There are several gene-insertion technologies, for example, a natural delivery system (*Agrobacterium*-mediated) or a physical delivery system (gene gun). Genetic engineering also has enabled the insertion of multiple resistance genes into corn hybrids, resulting in hybrids that may exhibit both herbicide and insect resistance. These types of hybrids are referred to as “stacked genes” hybrids and GE crops have generally had favorable economic outcomes for producers in early years of adoption, but enduring and widespread gains will depend on institutional support and access to profitable local and global markets, especially for resource-poor farmers (National Academies of Sciences, Engineering, and Medicine, 2016).

The development and introduction of genetically engineered crops has proceeded under tremendous controversy. Specific concerns related to the use of these crops include human health (potential allergenicity introduced by the inserted gene), environment (damaging to nontarget organisms; development of resistant biotypes), and economic (added costs, which may not be recovered, to pay for the technology). In addition, international market acceptance of genetically engineered crops perhaps has been one of the greatest stumbling blocks to their widespread introduction and use. Today, genetically engineered crops continue growing in a sustainable way and several countries are using this technology. According to the annual report of International Service for the Acquisition of Agri-biotech Applications (2016), the percentage of adoption to genetically engineering corn hybrids in the world is 33% compared with the traditional ones (Fig. 1.6). Novel technologies are coming to enhance the adequate control and management of pest in corn and other crops. For example, the use of “gene editing” by the technology of CRISPR (clustered regularly interspaced short palindromic repeats)-associated RNA-guided endonuclease Cas9, which can be easily targeted to virtually any genomic location of choice by a short RNA guide (Hsu et al., 2014).

Storage Management

The main purpose of grain storage is to equilibrate supply and demand and this postharvest operation is a key step in the complex logistics of moving grain from producers to processors and grain products from processors to consumers. Good storage practices are aimed to provide wholesome cereals, free of insect and mold damage, mycotoxins, pesticides, insect fragments, and rodent filth. The final target is to manage stored grain wisely with insignificant losses while maintaining its nutritional and functional qualities. Grains are preferably stored in weather- and pest-proof storage structures so that their viability, food energy, nutritional quality, and marketability can be assured. Grain elevators are centers where the grain is concentrated with the aim of preserving and improving the grain grade. Incoming lots of grains are, in most cases, sampled, analyzed (in order to assign class), graded (quality attributes), weighed, unloaded, cleaned, and stored. After sampling, most grain lots are inspected and graded by licensed inspectors or by experienced employees (Serna-Saldivar, 2010c).

The main operation for storage management includes: grain analysis, weighing and unloading, dehydration, cleaning, rotation, and aeration. For analysis, the main grain quality factors are moisture, test weight, dockage, heat damage, insect damage, and mycotoxins. Grain shipments are usually weighed on platform scales and then dumped into underground bins via gravity. Grains are elevated or conveyed using screw conveyors or buckets. The aim of this operation is to lower the grain moisture content to levels adequate for storage to maintain grain viability and to keep minimum grain physical

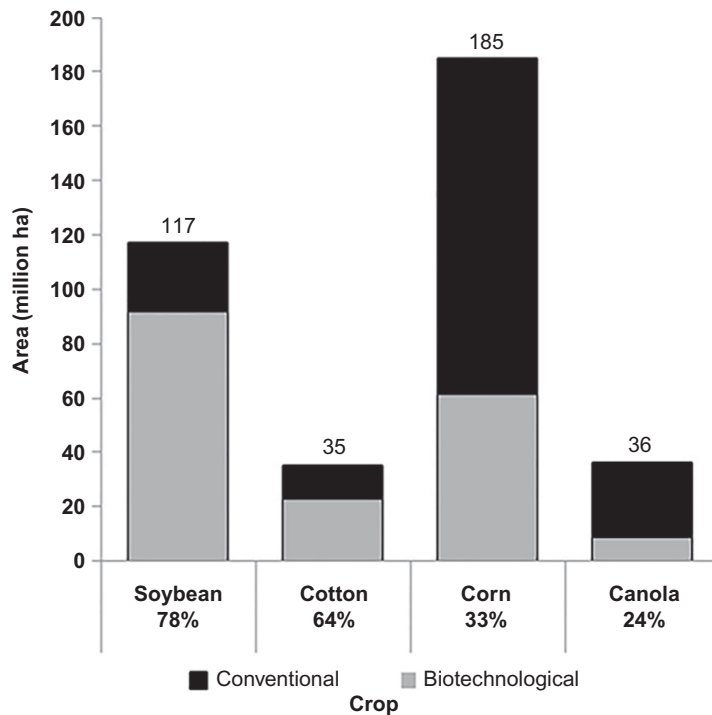


FIG. 1.6 Global adoption rate (%) for the principal biotechnological crops. (Source: *International Service for the Acquisition of Agri-biotech Applications, 2016. Global Status of Commercialized Biotech/GM Crops: ISAAA Brief No. 52. ISAAA, Ithaca, pp. 1–12.*)

damage such as stress cracks. Artificial drying is the most common practice to lower moisture content of cereal grains. Regardless of the dehydration technique, the principal factors to regulate are air temperature, relative humidity, airflow, depth of the grain, and the desired rate of dehydration. The cleaning system typically consists of air aspirators and sifters equipped with magnets to trap metals. Air aspiration removes most of the light contaminants such as plant material, glumes, and empty kernels, whereas milling separators are designed to remove contaminants larger and smaller than the grain. Turning is the process of moving bulk stored grains with conveyors within the storage facilities. The operation is practiced in order to break hot spots in storage, facilitate insect control, and make more efficient the aeration or ventilation operation. And finally, aeration is considered as the least costly prevention measurement for the preservation of grains. The aim of this operation is to equalize stored grain temperature to prevent moisture migration, remove sour and off-odors caused by molding, and cool the grain to prevent or minimize heat spots and insect and mold growth. Most aeration systems consist of perforated air ducts positioned in various configurations on the floor before the facility is filled (Serna-Saldivar, 2010c; Serna-Saldivar and Garcia-Lara, 2016).

GENERAL USES

In contrast to rice and wheat, corn is mostly utilized for animal feeding and bioethanol production (Fig. 1.7). According to the Food and Agricultural Organization in 2016, approximately 85% of maize was used for animal feeds (see Chapter 23) and bioethanol (see Chapter 22). Of the approximately 320 million metric tons produced in the USA during 2016, 45%, 42%, and 13% were used respectively for animal feed, bioethanol, and food/seed/industrial purposes.

The main use of corn is as a foodstuff for both monogastric and ruminant animals and diverse aquatic species that provide eggs, milk, meat products, fish, and crustaceans. In many prepared diets, ground or processed corn (i.e., reconstituted, steam flaked, pelleted, extruded, micronized, and popped) constitutes up to 70% of the diet. Corn is also used for the preparation of pet food. Corn is the preferred feedstock because it is relatively cheap, palatable, readily digested, and widely available around the globe. Cereals are bio-transformed into animal products that possess an excellent protein quality and digestibility and provide some essential nutrients that are scarce in cereal-based food (i.e., calcium, iron, vitamin B₁₂). Additionally, the minerals and vitamins associated to animal products are more bioavailable to the human system. Poultry and swine diets usually contain up to 70% of maize products, whereas feedlot rations up to 90%. The feed industry formulates feeds from whole corn and the wide array of coproducts obtained from the dry-milling (see Chapter 15), wet-milling (see Chapter 18), and brewing and bioethanol industries (see Chapter 22). The main use of corn is as a source of highly digestible energy, although some by-products are rich in fiber, fat, or protein. Corn alone is not capable of

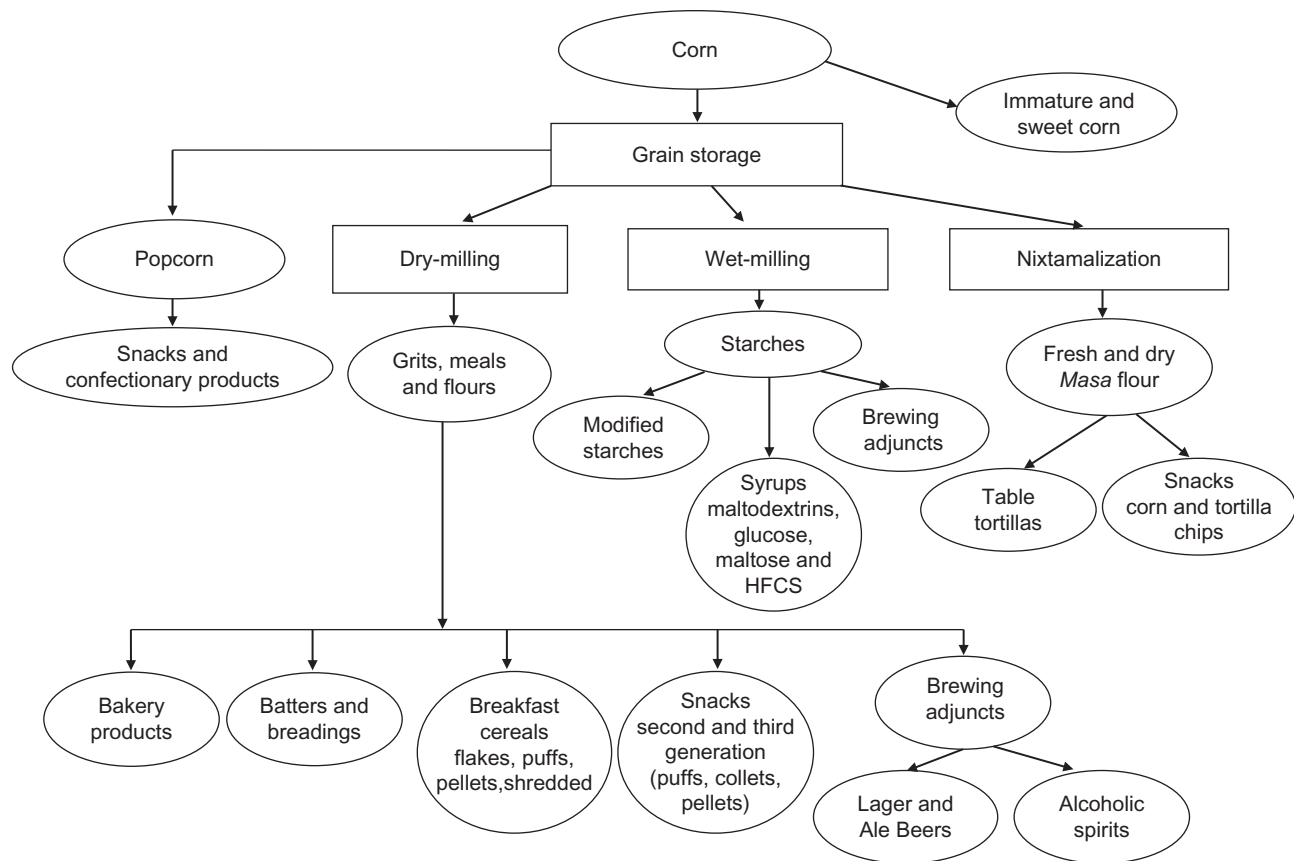


FIG. 1.7 General scheme of the main food uses of corn.

sustaining growth in most domestic animals, especially in the early stages of development, because of the lack of the protein quality required for optimum growth. The corn protein is not well-balanced in terms of essential amino acids; therefore, most feeds are supplemented with legume or oilseed proteins. The most widely used sources are soybean protein for monogastrics and canola, cottonseed, and other defatted meals for ruminants (Serna-Saldivar, 2008).

Most feed corns are yellow, dent, and soft-textured. These kernels are easier to mill into flour and have higher rate of both protein and energy digestibility. As a result, corn is considered to have the highest energy value for all domestic animals. The high-lysine and tryptophan corns, named QPM, can reduce the usage of protein feedstuffs such as soybean meal. Many studies have been conducted comparing regular corn versus QPM. Results clearly show that QPM has higher nutritional value due to improved protein quality. Dry matter, energy, and protein digestibility are comparable, but nitrogen retention improves due to the higher levels of lysine and tryptophan. Thus, diets based on high-lysine cereals require less protein supplementation, which provides an economic incentive especially for poultry and swine farmers (Serna-Saldivar, 2008).

The recent boom in the production of corn bioethanol has increased the availability of the main coproduct known as dry distilled grains (DDGS). In the USA, nearly 40 million tons of DDGS were produced in 2016 with an estimated market value of 4 billion dollars. Corn DDGS is considered as an excellent energy and protein source for beef and dairy cattle and an important feed ingredient for use in swine and poultry (layer, broiler, duck, and turkey) diets where it contains approximately 85% of the energy value of corn (US Grain Council, 2015a, b).

Large quantities of corn are channeled to biorefineries for the production of fuel ethanol. In the USA, more than 130 million tons were bioconverted into 52 billion liters of anhydrous ethanol for production of E10 gasolines. There are three corn-based feedstocks used for ethanol: whole grain known as dry grind, modified dry grind or use, or dry-milled fractions/refined starch. The most practiced is the dry grind. In this process, the grain is simply ground and then subjected to the three sequential steps: starch conversion into glucose, yeast fermentation, and distillation. The yield of one ton of yellow dent maize ranges from 380 to 400L. In the modified dry grind process, the grain is dry-milled with the aim of removing the pericarp and germ and the resulting endosperm pieces further ground into a meal that is processed similarly as the whole

ground maize of the dry grind process. The advantage of this process is higher yields (410–420 L/ton), the beforehand separation of shelf-stable bran and germ coproducts, and the recovery of lower amounts of spent grains with lower fiber content. The least common way to obtain fuel ethanol is by converting starch slurries obtained after conventional wet-milling. The main disadvantage of using starch slurries is that the wet-milling process demands important amounts of energy and more capital investments. The advantages are the recovery of the typical wet-milling coproducts and the high ethanol yield. Approximately 540 L ethanol is obtained from 1 ton starch (see [Chapter 22](#)).

The main use of fuel ethanol is to oxygenate gasoline instead of the hazardous methyl tertbutyl ether (MTBE). Most ethanol programs start with the substitution of MTBE in the gasoline, so E7.5 gasoline is produced. Then fuels with higher levels of ethanol are produced (E10, E15, and E20). When ethanol substitutes more than 15% or 20% of the gasoline, the motors have to be adjusted especially modifying the carburetor. From the environmental viewpoint, the ethanol burns more cleanly because it produces less carbon monoxide, nitrogen oxides, sulfur oxides, suspended particles, and other contaminating hydrocarbons. Other important advantage of ethanol is that, when accidentally spilled, it does not affect as much the ecosystems because it decomposes in approximately 1 week.

The postharvest management of corn destined for direct human consumption typically comprises three sequential stages before reaching the consumer: storage, milling, and food manufacturing ([Fig. 1.8](#)). In most instances, corn is stored for different periods of time because it is usually harvested in specific periods of the year or, when imported, are usually acquired in large quantities. The storage practices of corn are aimed towards prevention of both intrinsic and extrinsic deterioration, which are costly due to dry matter losses and loss of quality as raw material for further processing. Corn is mainly channeled to three distinctive milling industries: dry and wet-milling and dry *masa* flour (see [Chapters 15, 17, and 18](#) respectively). Most maize dry-milling processes consist of degerming kernels with the aim of obtaining an array of refined grits with different sizes, meals, and flours free of pericarp and tip cap tissues. These dry-milled fractions are widely used as raw materials for production of breakfast cereals, snacks, brewing adjuncts, bakery products, and as important ingredients for batters and breadings (see [Chapter 16](#)).

Wet-milling is aimed towards the production of refined or prime corn starch (refer to [Chapter 18](#)) and generates important coproducts such as germ, bran, and corn gluten meal. The germ is usually channeled to the oil-crushing industries for the extraction of refined corn oil (see [Chapter 21](#)), whereas the other coproducts are widely used as animal feeds. Starch is the raw material for further production of sweeteners and modified starches (see [Chapters 19 and 20](#)). Most of the starch is enzymatically converted into maltodextrins, maltose, glucose, and high-fructose syrups. The production and utilization of these syrups have increased during the past decades because the soft drink industries prefer to use sweeteners instead of crystallized sugar.

The milling of corn into fresh *masa* and shelf-stable dry *masa* flour is gaining popularity worldwide because this process yields tortillas and fried snacks such as corn chips and tortilla chips widely consumed all over the world (see [Chapter 17](#)). Three major products are industrially produced from lime-cooked corn: table tortillas, corn chips, and tortilla chips. Corn and tortilla chips are primarily produced and consumed in developed countries, where they have an important share within

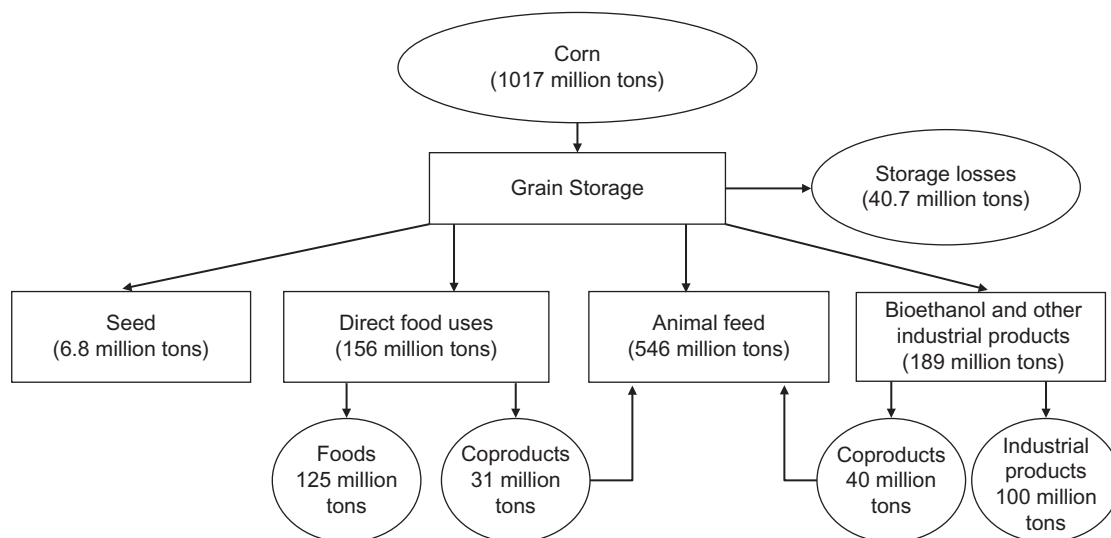


FIG. 1.8 Postharvest losses and corn utilization in year 2013.

the salted snack food market, whereas table tortillas constitute the staple food for large groups of people in Mexico and other Latin American countries. These products can be produced using fresh *masa* or industrially manufactured dry *masa* flour. The use of dry *masa* flour is rapidly growing because of its convenience (Serna-Saldivar, 2008, 2015).

Specialty corns have been selected due to their unique properties (Table 1.5), the most important being popcorn, sweet, high-amylose, waxy, blue, and quality protein (see Chapter 10, Hallauer, 2000). Popcorn has been a favorite traditional snack worldwide for more than a century, whereas sweet corn is one of the most popular canned or frozen vegetables in the USA and Canada (Serna-Saldivar, 2008). Large quantities of waxy maize, which contains more than 95% amylopectin, are channeled to the wet-milling industry with the aim of obtaining starch with unique properties and functionality. As mentioned before, QPM contains almost twice as much lysine and tryptophan than regular counterparts. Thus, QPM-based food can upgrade the nutritional status of infants who consume cereals daily in marginal areas around the world. The future of QPM looks promising because of its upgraded nutritional value and the recent development of

TABLE 1.5 Major Uses and Properties of Regular and Specialty Corns

Type of Corn	Uses
Yellow and White	Yellow dent corn is the most popular worldwide and is used for animal feed, starch production, and bioethanol. White corn is popular in several regions of the globe like Mexico. It is used for tortillas and production of traditional food. The Food-Grade yellow and white genotypes were developed for lime-cooking and dry milling
Popcorn	Special kind of flint corn. Yellow or white hybrids were bred to contain high proportions of translucent, flinty, or vitreous endosperm and give high expansion rates when popped. Most commercial popcorn has a 30- to 40-fold expansion. The pericarp and outer layers of the kernel participate directly in the popping action by serving as a pressure vessel enclosing the endosperm
Blue	Blue corn is a floury or soft endosperm type that generally grows in long ears (8–12 rows) in highlands. The aleurone layer contains anthocyanins that impart the blue appearance. Blue corn is especially prized as ceremonial maize by the North American Indian tribes and is currently being used to produce organic flours and food such as table tortillas and fried tortilla chips
Sweet	Sweet corn have recessive genes (sugary 1 or su1, sugary 2 or su2) that cause an alteration in the endosperm that results in higher levels of soluble sugars and reduced levels of starch in the kernel. Sweet corn hybrids have been developed specifically to produce corn with desirable color, sweetness, and tenderness for on the cob consumption or frozen or canned
Waxy	Waxy starch is composed of more than 95% amylopectin. It is utilized mainly by the wet-milling industry. Waxy starch has a higher hot viscosity and produce softer, more stable and clearer gels due to its lower retrogradation. It also has higher freeze-thaw stability
High-amylose maize	Also named amylo maize that expresses high quantities of linear amylose due to recessive <i>ae</i> gene. Amylo maize contain amylose from 37 to 65% and has potential for the paper, textile and adhesive industries, produces rigid opaque gels with potential for the confectionery industry and for production of biodegradable packaging materials that resemble polystyrene foam
Cuzco/Cacahuacintle	The Cuzco corn comes from 8-rowed ears that produce the largest known kernels. Cuzco corn grows at high altitudes and produces white kernels with soft endosperm texture and bland flavor. Cuzco corn is mainly used to manufacture Cornnuts™ and <i>Cacahuacintle</i> kernels for <i>hominy</i> and <i>pozole</i> production
Quality protein maize (QPM)	QPM has the opaque-2 gene that contains twice as much lysine and tryptophan compared to regular counterparts, and therefore, has better protein quality. Harder QPM corns are suited for dry-milling and alkaline cooking, while soft hybrids for use in wet-milling to produce sweeteners, starches, and alcohol would be desirable since the coproducts would be more valuable
High-oil corn (HOC)	Improved high-oil corn (HOC) genotypes contain more than 6% oil. HOC types have been bred for temperate, subtropical, and tropical environments using conventional recurrent selection. HOC hybrids contain more protein, lysine, fat, and metabolizable energy than normal corn. The main potential of Hoc is for animal feeding, especially monogastrics and probably for oil-crushing industry
Baby corn	Special maize varieties are grown and shucked immediately after pollination when the ears are 1–2 in. long. These small ears are used as pickles and other tasty snacks in salad bars. Most of the baby corn used is produced in Thailand and exported to Europe and North America

Source: Hallauer, A.R., 2000. Specialty Corns. CRC Press, Boca Raton, pp. 1–496. Lambert, R.J., 2000. High oil corn hybrids. In: Hallauer, A.R. (Ed.), Specialty Corns. CRC Press Inc., Boca Raton, pp. 123–145. Serna-Saldivar, S.O., 2010a. Physical properties, grading and specialty grains. In: Cereal Grains: Properties, Processing and Nutritional Attributes. CRC Press, Boca Raton, pp. 43–81.

high-yielding varieties and hybrids that produce kernels with different physical properties. Blue maize has a pigmented aleurone that imparts an intense blue color and unique flavor. It has been traditionally dry-milled for production of flours or meals and also used for tortillas and chips. It has high levels of anthocyanins and other phenolics with proven nutraceutical properties (see [Chapter 14](#)).

CONCLUSIONS

Undoubtedly, corn is the most relevant cereal crop in terms of annual production with yearly productions exceeding 1 billion tons. The great success of the crop is due to its wide adaptation to different ecosystems, the development of high-producing open-pollinated varieties and hybrids which include traditional and genetically modified maize, the great response to fertilization, and its high nutritional value especially in terms of digestible energy contribution to both humans and domestic animals. Corn evolved from wild teosinte about 10,000 years ago in Mesoamerica and was greatly responsible for the initiation of formal agriculture in Mesoamerica and the rapid growth of ancient cultures. We inherited from these native Mesoamerican cultures primitive corn races, including specialty types such as popcorn, sweet, pigmented, high oil, and quality protein, which constitute the genetic background for the production of high-yielding varieties and hybrids. From the utilization viewpoint, corn is mainly used by the feed, food, or biofuel industries. Corn utilized for production of both monogastric and ruminant feedstocks provides eggs, poultry and pork meats, beef, milk, and even fish and crustaceans. In terms of direct food use, corn is generally consumed on the cob or mature kernels channeled to the dry, wet, or nixtamalization milling industries that generate intermediate products that are further transformed into breakfast cereals, snacks, tortillas, bakery items, different syrups and sweeteners, beer, and potable alcoholic beverages. During the past decade, corn has gained relevance as industrial raw material for production of biofuels, particularly bioethanol. The future of corn looks bright because this C4 crop is one of the most versatile and high producing with very important nutritional and economic implications because it is the main staple for many people around the globe, constitutes the base for production of much needed animal products, and is gaining importance for production of value-added industrial products including renewable biofuels. The main constraints of corn are the climate changes, the need for more diverse biotechnological varieties, and novel strategies to face the relatively high losses still experienced during storage especially in developing countries and its high susceptibility to contamination with toxicogenic molds.

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