17. Breeding Corn (Maize)

Corn, or maize (*Zea mays* L.), is the world's third leading cereal crop, after wheat and rice. The United States produces nearly 40% of the total world production. The next largest corn-producing countries are the People's Republic of China and Brazil. Corn is the leading grain crop in the United States, with average production (metric tons) approximately three times that of wheat, the next leading grain crop. Corn is the primary food grain in Mexico, Central America, and the Andean region of South America, and is important as a food grain in eastern and southern Africa and China. In the United States, corn is used primarily as a feed grain for livestock and for industrial products.

Corn is a naturally cross-pollinated crop, and due to its uncontrolled pollination is often referred to as being *open-pollinated*. The principal contributions to corn improvement during the twentieth century have been:

- a method for breeding hybrid corn and development of the infrastructure for large-scale, commercial production of hybrid seed, and
- genetic improvements in the corn plant that contribute to its increased productivity, earlier maturity, stronger root systems which combined with shorter and stronger stalks reduce lodging, and resistance to destructive disease pathogens and insect pests.

Because of the important place of corn in United States agriculture, it is appropriate that a system for breeding hybrid corn is the foremost contribution of United States scientists in plant breeding.

ORIGIN OF CORN

The corn plant is indigenous to the Americas and was the principal food grain of Native Americans. Corn was domesticated about 8000 years ago and is no longer capable of survival in its wild form. During the centuries that corn was cultivated before Europeans came to the Americas, Native Americans accomplished remarkable feats by evolving races of flint, flour, gourdseed dent, pop, and sweet corn. Building on this legacy, early American farmers evolved high-yielding, open-pollinated dent cultivars adapted to the central Corn Belt and the eastern and southern regions of the United States, and early maturing flint cultivars for northern United States. Modern corn cultivars differ from primitive corn in having more productive plants due to an increased number and weight of individual kernels on a cob of corn.

How corn evolved and its early progenitors have been vexing matters of speculation. It now seems to be generally accepted that corn originated from *teosinte*, the nearest known relative of corn. There is still discussion as to whether corn originated by a single domestication from the basal branching teosinte subspecies *Zea mays* L. spp. *parviglumis*, or from the lateral branching subspecies *Z. mays* L. spp. *mexicana*, or by a dual domestication from the two subspecies (Fig. 17.1). Teosinte is native to Mexico and Guatemala and in its native habitat may be found growing wild in cultivated fields of corn. The wild annual forms of teosinte have the same chromosome number as corn and cross readily with corn to produce fertile hybrids. Teosinte, like corn, is monoecious in flowering habit, with staminate and pistillate flowers borne in separate inflorescences; it differs from corn in that the pistillate spikes bear 6 to 12 kernels in hard triangular, shell-like structures. The teosinte seed structures break apart and shatter when mature, forming a natural means of seed dispersal.

The geographic origin for a crop species is identified by locating areas in which there are large numbers of diverse types. On this basis, corn has two possible centers of origin; the highlands of Peru, Ecuador, and Bolivia; and the region of southern Mexico and Central America.

RACES OF CORN

Beginning in 1943, several thousand local varieties of corn were collected in Mexico, Peru, Bolivia, Brazil, Guatemala, and other countries of Central and South America by scientists from the Rockefeller Foundation, the United States Department of Agriculture, and the Mexican Ministry of Agriculture. Local varieties from the same geographic area that had similar morphological, physiological, genetic, and cytological characteristics were grouped together into more or less distinct races. The classification of local varieties into races facilitated the breeder's search for germplasm containing particular characters of use in the breeding program. Unfortunately, many of the original collections were lost because a centrally located and adequately equipped storage facility was not available at that time. New collections have been made and over 13,000 germplasm accessions are currently stored in new facilities at the International Maize and Wheat Improvement Center (CIMMYT) in Mexico, with duplicate storage in Colombia, Peru, and the United States National Seed Storage Laboratory at Fort Collins, Colorado.

Varieties of corn indigenous to the United States, except for sweet corn and popcorn, have been classified into 9 or 10 racial groups, the most important races being the *Corn Belt dents*, the *southern dents*, and the *northern flints*. Within these races, early farmer-breeders developed open-pollinated varieties by repeated selection for particular plant and ear characteristics. These open-pollinated varieties later became the germplasm base from which modern hybrid corn cultivars were developed. Open-pollinated varieties are no longer grown by farmers in the United States, having been replaced by hybrid corn, but are still grown in some underdeveloped countries.

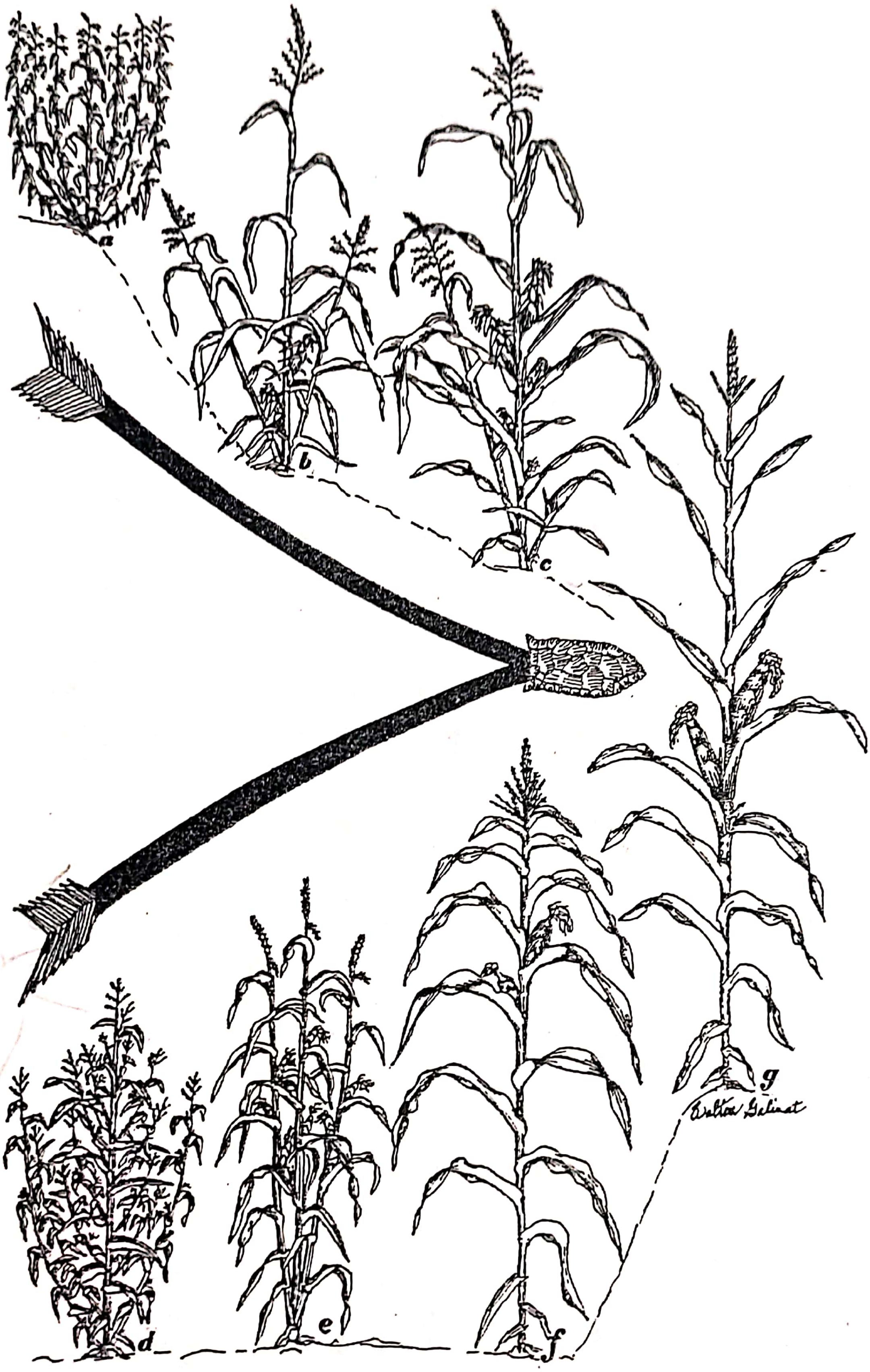

FIG. 17.1. Proposed pathways for double origin of corn from different subspecies of teosinte. Upper: Basal branching type from subspecies *parviglumis*. Note proliferation of tillers at the base of the plant. Lower: Lateral branching type from subspecies *mexicana*. Note that branching is lateral, with each branch terminating in a tassel. (After W.C. Galinat.)

GENETICS AND CYTOGENETICS

Corn is a diploid species with chromosome a number of $2n = 2x = 20$. It has been the object of more intensive genetic and cytogenetic studies than any other crop species as the result of:

- the economic importance of corn as a field crop in the United States,
- the ease with which corn can be genetically manipulated by either self- or cross-pollination,
- the large number of seeds obtained from a single pollination,
- the easily observed plant and seed characters available for study,
- the recovery of many recessive alleles by inbreeding or use of mutagenic agents,
- the small number of chromosomes; corn is a diploid species ($n = 10$), and
- the ability to recognize individual chromosomes under the microscope from their length and the presence on them of distinctive knobs.

Genetic studies on corn have contributed substantially to understanding genes and gene action, the mutation process, heterosis, and quantitative genetic theory. In the breeding of corn, a cross-pollinated species, quantitative genetics has a more important role than in the breeding of self-pollinated species. The system of breeding hybrid corn originated from a genetic study, an event that stimulated further genetic investigations in the corn species. In addition to the abundance of natural variation in the species, new mutant forms are readily induced by radiation and chemical mutagens. The genetic mapping of the corn genome is more complete than for any other plant species. More than 1000 loci have been studied, and the positions of more than half of the loci have been established on linkage maps of the 10 chromosomes. The gene symbols, chromosome location, name, and phenotype of the genes studied are recorded annually in a *Maize Genetics Cooperation Newsletter*, published by the United States Department of Agriculture and the Department of Agronomy, University of Missouri, Columbia. Genetic stocks of corn are maintained and made available to research scientists from the Maize Genetic Stock Center, University of Illinois, Urbana-Champaign.

MOLECULAR BIOLOGY

The considerable information generated from the genetic mapping of the corn nuclear genes heightened interest in the molecular mapping of genetic markers in the corn genome by restriction fragment length polymorphism (RFLP) techniques and other means and the utilization of the molecular markers as breeding tools. The RFLP technology has the potential for screening inbred lines for specific genetic traits. An RFLP marker associated with a nuclear gene for a character difficult to identify from visual observation of the corn plant would be useful in locating the nuclear gene on the chromosome and in identifying other corn plants possessing the gene.

The insensitivity of monocots such as corn to *Agrobacterium* infection has limited the effectiveness of this procedure for genetically transforming the corn plant, but the particle-gun technique offers a potential, reproducible system by which transformation can be attained in corn. Regenerating plants through cell and tissue culture techniques is a prerequisite for creation of transgenic plants. Transformation in corn will be facilitated by the information generated by the molecular mapping of the corn chromosomes. Transformation does not replace conventional breeding procedures, but it provides a new breeding tool whereby DNA may be inserted into the corn genome from a wider range of donors than is possible by traditional cross-fertilization procedures.

FLOWERING AND POLLINATION

The corn plant has *monoecious* flowering structures with *staminate* flowers borne in the tassel and *pistillate* flowers borne on a shoot midway of the stalk. Pollination is consummated by transfer of viable pollen from the staminate flowers in the tassel to the silks, the receptive organs of the pistillate flowers. Wind is the principal agent in the uncontrolled or *open-pollination* of the corn plant. Normally, about 95% of the ovules on a shoot are cross-pollinated and 5% self-pollinated. Most of the pollen that pollinates an ear of corn comes from plants in the immediate vicinity, although the pollen may be carried by the wind for great distances. It is not uncommon to observe occasional yellow grains in ears of white corn even though the nearest field of yellow corn from which the pollen could have originated was 1000 m distant.

The main stem of the corn plant terminates in a tassel which bears two-flowered staminate spikelets, each flower having three anthers (Fig. 17.2). As the tassel flower opens, the anthers are pushed out by elongating filaments (Fig. 17.3), and pollen grains are emptied from the extruded anthers. A single tassel from a normal plant may produce 25,000,000 pollen grains, or an average of over 25,000 pollen grains for each kernel on an ear of corn. Pollen shedding usually begins one to three days before the silks emerge from the shoots of the same plant and continues for three to four days after the silks on the plant become receptive to pollen. The pollen may be killed by temperatures above 35°C (95°F) during the pollination period. Considering the large number of pollen grains produced, seed set is normally unaffected if 10% of the pollen grains survive. In the breeding nursery where pollen supply may be limited, high temperatures can severely reduce seed set.

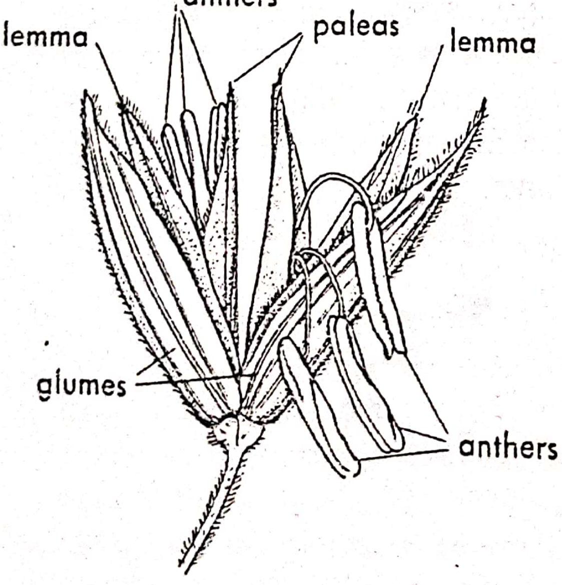

FIG. 17.2. Staminate spikelet of corn. Staminate spikelets are two-flowered, each with three anthers.

The ear shoots arise as branches from nodes about midway on the stalk. Each shoot is composed of a shank from which the husks arise and terminates in the cob on which the pistillate flowers are borne (Fig. 17.4A). The spikelets are borne in pairs, each spikelet normally containing one fertile and one sterile ovule, resulting in an even number of rows of kernels on the ear. Fertilization of the second ovule produces crowded and irregular rows of kernels on the ear. The silks are attached to the tip of the ovary (Fig. 17.4B). The silks function both as stigma and style and are receptive to fresh pollen throughout their entire length. Fertilization of the ovule usually occurs within 12 to 24 hours after the