

CORN NATIONAL CORN HANDBOOK

THE CORN CROP

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Origin, Adaptation, and Types of Corn

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ORIGIN OF CORN

Corn (*Zea mays* L.) is the only important cereal indigenous to the Western Hemisphere. Apparently originating in Mexico, it spread northward to Canada and southward to Argentina. While the possibility of secondary centers of origin in South America cannot be completely ruled out, the oldest (7000 years) archaeological corn was found in Mexico's Valley of Tehuacan.

The earliest "corn" of which there is record is unmistakably corn. The female inflorescence of this 5000 B.C. corn had reached a degree of specialization that precluded the possibility of natural seed dissemination. Thus, the oldest corn of record was dependent upon man for its survival.

Numerous theories of origin have been offered over the years, only two of which receive serious consideration today. One is that teosinte (*Zea mexicana*) is the wild progenitor of corn; the other is that a wild pod corn, now extinct, was the ancestor of domesticated corn. While perhaps more students of corn seem to accept the first theory, others are equally convinced of the second.

Aside from its possible role in the origin of corn, teosinte has had major impact on its evolution. In Mexico particularly, introgression between corn and teosinte has likely occurred for centuries and continues to this day. The effects are apparent in the morphology and cytology of both species. There is also reason to believe that genes for resistance to certain viruses have reached corn through its introgression with teosinte.

The origin of corn may never be known with certainty. One reason is that the hypotheses purporting to explain origin cannot be tested experimentally. Therefore, science would perhaps be better served if less

attention were given to determining corn's origin and more to understanding the remarkable variability found within the species.

Variability and Races

Regardless of origin, corn has proven to be one of the most adaptable and variable members of the grass family. Its evolution, a large part of which apparently occurred under domestication, has resulted in biotypes with adaptation ranging from the tropics to the north temperate zone, from sea level to 12,000 feet altitude and growing periods (planting to maturity) extending from 6 weeks to 13 months.

Almost 300 races of corn have been described from Mexico, Central and South America, and the Caribbean. Although many appear synonymous, at least 150 distinct entities have been collected in these areas. It was from certain of these races that most of the corns of North America were ultimately derived.

Spread from Center of Origin

Following discovery, corn moved quickly to Europe, Africa and Asia. From Spain, it spread northward to the short-growing-season areas of France, Germany, Austria and eastern Europe, where selection for early maturity has produced some of the earliest commercial varieties of corn now available. In Italy and Spain, early counterparts of many South American races are evident even today.

Although introduced into Africa soon after discovery, much of the corn now found in that continent is derived from later introductions from the southern U.S., Mexico and parts of eastern South America. Most of southern Africa's corn traces back to varieties grown in the southern U.S. in colonial and post-colonial times. Corn

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of tropical middle (lowland) Africa is similar to the lowland and tropical corns of Central and South America.

The most widely used and productive corns of Asia are derived from Caribbean-type flints introduced in relatively recent times. However, older and quite distinct types of corn can also be found, for example, among the hill people of Mindanao in southern Philippines. Included are some small-eared, early-maturing flints or pops that either have the capacity to grow and mature quickly before being devastated by downy mildew or carry some genetic resistance to downy mildew.

In the eastern Himalayas (Sikkim and Bhutan), a distinctive type of popcorn is found whose Western Hemisphere progenitors seem to have disappeared. When and how the ancestor of this corn reached Asia is not known. However, since it is not present on the Indian subcontinent to the south, it may have reached the Himalayas by way of China and Tibet. In any event, a search for similar corns in south China and Tibet would seem justified.

Corn of the U.S. Corn Belt

Whereas most of the modern races of corn are derived from prototypes developed by early native agriculturists of Mexico, Central and South America, one outstanding exception is solely the product of post-colonial North America—the yellow dent corns that dominate the U.S. Corn Belt, Canada and much of Europe today. The origin and evolution of this remarkable race of corn have been clearly documented and confirmed.

In the early 1800s, two predominant races of corn of North America's eastern seaboard—the late-maturing Virginia Gourdseed and the early-maturing Northeastern Flints—were first crossed, and the superiority of the hybrid recognized and described. The cross was repeated many times during the western migration of settlers; and out of these mixtures eventually emerged the Corn Belt dents, the most productive race of corn found anywhere in the world.

It was the highly selected varieties of Corn Belt dents that formed the basis of hybrid corn and the source of the first inbred lines used to produce hybrids. Germplasm from some of these varieties (Reid, Lancaster, Krug, etc.) still figure prominently in the ancestry of hybrids used in the Corn Belt even to this day.

ADAPTATION OF CORN

Definition and Adaptation Worldwide

Adaptation in corn means good performance with respect to yield and other agronomic characteristics in a given environment. The environment includes all conditions to which the plant is subjected during the growing season (from pre-seedling emergence to harvest maturity).

The major environmental factors are: (1) daily maximum and minimum temperatures, (2) soil atmosphere

and moisture levels, (3) humidity of the atmosphere immediately surrounding the plant, (4) wind movement, (5) day length, (6) light intensity, (7) air pollution, (8) soil type, (9) soil fertility, (10) number of days exceeding 50°F, (11) competition from other plants including its intended neighbors as well as weeds, and (12) the disease-insect complex.

Many of these factors interact in a complex manner to produce stress on the plant. The plant's reaction to stress is under genetic control, and differences among hybrids exist. Corn breeders are continuously developing and testing new genetic combinations in differing environments to find types that give the best agronomic performance over a range of geographical locations and years.

Corn is grown from sea-level to altitudes of more than 12,000 feet and from the equator to about 50° north and south latitudes. Compared to environmental conditions of the U.S. Corn Belt, many producing areas would be considered very much substandard. In harsh-environment areas, the varieties grown would be considered adapted because they responded the best under the unfavorable growing conditions. The original open-pollinated varieties have become adapted through selection over time by both man and the environment.

Adaptation Within the Corn Belt

World production of corn in the early 1980s approached 450 million metric tons annually, with the U.S. contributing over 48 percent of the total. Of U.S. annual production, the 13 Corn Belt states account for about 82 percent.

No area of the world equals the Corn Belt for high yields. This is due to a combination of ideal soils and climate, advanced farmer know-how, and the success of corn breeders in developing hybrids with high genetic potential.

Climate. Corn is considered a warm-weather crop. In the Corn Belt, average summer temperatures range from 70° to 80°F daytime and exceed 58°F at night. The average frost-free growing period is over 140 days. Greatest yields are obtained where 30 or more inches of rain occur during the growing season. In areas where rainfall is less than 20 inches, yields are much reduced unless irrigation is used.

Rainfall distribution greatly influences maximum yields, especially for the 3-week period centered around tasseling. In the southern part of the Corn Belt, high-temperature stress and rainfall deficiencies often occur in late July and August. Therefore, farmers of this region try to avoid having corn tassel during this dry, hot period by planting earlier and using earlier-flowering hybrids.

Maturity. Maturity of corn hybrids is a genetic characteristic and is generally defined as the period from germination to when the kernel ceases to increase in weight. In the northern Corn Belt, early hybrids often reach physiological maturity in less than 100 days; whereas in the extreme south, 150 or more days may

be needed. These day periods are measures of relative maturity.

Hybrids have traditionally been classified into 15 maturity groups ranging from Agricultural Experiment Station (AES) 100 to AES 1500 (earliest to latest). However, maturity classification can be made more precise by determining the total heat units required from emergence to physiological maturity. A heat unit measure commonly used accumulates the daily excess of average temperature over 50°F, where:

$$\text{average temperature} = (\text{maximum} + \text{minimum}) \div 2.$$

Early hybrids grown in the northern Corn Belt classified as 100-day maturity may require 90 or less days to reach maturity when grown further south where heat unit accumulation is more rapid.

Adapted hybrid development. Hybrids have been developed that are adapted from Nebraska to Ohio. However, the environmental conditions differ widely from west to east especially rainfall patterns, daily minimum and maximum temperatures, and the disease complex. For example, the hotter, drier conditions of the western Corn Belt are less favorable for leaf diseases caused by *Helminthosporium* spp. and anthracnose, but more conducive to viral infection, bacterial wilt and smut. For this reason, development of hybrids adapted from west to east has been relatively difficult and requires large-scale testing over a number of locations and years.

Number of frost-free days decreases from the southern to northern Corn Belt; however, hours of daylight on June 22nd are much longer in the north than in the south. Sunlight intensity is greater in the western and northern Corn Belt because these sections have less cloudy weather.

The result of intensive corn breeding efforts over the past four decades has been better adaptation to the many environments under which corn is grown.

TYPES OF CORN

Corn variation may be artificially defined according to kernel type as follows: dent, flint, flour, sweet, pop and pod corn. Except for pod corn, these divisions are based on the quality, quantity and pattern of endosperm composition in the kernel and are not indicative of natural relationships.

Endosperm composition may be changed by a single gene difference, as in the case of floury (*fl*) versus flint (*Fl*), sugary (*su*) versus starchy (*Su*), waxy (*wx*) versus non-waxy (*Wx*), and other single recessive gene modifiers that have been used in breeding special-purpose types of corn. The quantity or volume of endosperm conditioning the size of the kernel (e.g., the difference between dent and flint corns or flint corn and popcorn) is polygenic and, in the latter example, is of some taxonomic significance.

The pod corn trait is monogenic and more of an ornamental type. The major gene involved (*Tu*) produces long glumes enclosing each kernel individually, such as occurs in many other grasses.

Dent Corn

The U.S. Corn Belt dents originated from the hybridization of the Southern Dent or late-flowering maize race called Gourdseed, and the early-flowering Northern Flints. Dent corn is characterized by the presence of corneous, horny endosperm at the sides and back of the kernels, while the central core is a soft, floury endosperm extending to the crown of the endosperm where, upon drying, it collapses to produce a distinct indentation. Degree of denting varies with the genetic background. Nearly all varieties grown in the U.S. are yellow, with only a few white endosperm types grown.

Dent corn is used primarily as animal food, but also serves as a raw material for industry and as a staple food. Upwards of 93 percent of dent corn produced (including the corn equivalent of by-product feeds from corn processing) is used as animal feeds. However, it is still an important human food and industrial material, entering into many specialized products via the dry- or wet-milling industry in the U.S.

Yellow dent corn sells at market price as it enters the normal feed grain or milling channels. However, white dent often receives a premium price in the dry-milling industry, where it is utilized for certain human food products because of its whiter starch.

Flint Corn

The flint corns mostly have a thick, hard, vitreous (glassy) or corneous endosperm layer surrounding a small, soft granular center. The relative amounts of soft and corneous starch, however, vary in different varieties. Generally, the kernels are smooth and rounded, and the ears long and slender with a comparatively small number of rows or kernels. In temperate zones, flint corn often matures earlier, germinates better, has more spring vigor, more tillers and fewer prop roots than dent strains.

Very little flint corn is produced and utilized in the U.S. today, although it was undoubtedly grown extensively up through colonial times. Generally, yields are lower than our Corn Belt dents, in part because of relatively little breeding work done. Flints are more extensively grown in Argentina and other areas of South America, Latin America and southern Europe where they are used for feed and food.

Flour Corn

This is one of the oldest types of corn, tracing back to the ancient Aztecs and Incas. American Indians ground the soft kernels for flour. Floury maize types have soft starch throughout, with practically no hard, vitreous endosperm and thus are opaque in kernel phenotype. Kernels tend to shrink uniformly upon drying, so usually have little or no denting. When dry, they are easy to grind, but may mold on the mature ear in wet areas.

In the U.S., flour corn has limited production and is restricted to the drier sections. It is grown widely in the Andean region of South America.

Sweet Corn

The following genetic model featuring primary isolation groups for naming “vegetable corns” has been suggested by the industry:

- I. Sugary mutants
 - A. Standard sugary (*su*)
 - B. Augmented sugary
 1. Partial modification
 - a. Heterozygous shrunken -2 (*sh2*)
 - b. Heterozygous sugary enhancer (*se*)
 - c. Heterozygous shrunken -2 and sugary enhancer (*sh2* and *se*)
 2. Complete (100%) modification
 - a. Homozygous sugary enhancer (*se*)
- II. Shrunken-2 (*sh2*)
- III. Brittle (*bt*)
- IV. Brittle -2 (*bt2*)
- V. Amylose-extender (*ae*) Dull (*du*) Waxy (*wx*)
- VI Dent (vegetable)
- VII. Additional classes as new genes are used

Isolation will be required between major groups identified by a Roman numeral. Isolation is suggested but not required between subgroups within a major group. No isolation is needed for cultivars within the same classification.

Standard sugary kernel types. Sweet corn, commonly referred to as the standard sugary (*su*) corn, is thought to have originated from a mutation in the Peruvian race Chullpi. Most certainly it was grown and used by native American Indians in pre-Columbian times.

In sweet corn, the sugary gene prevents or retards the normal conversion of sugar into starch during endosperm development, and the kernel accumulates a water-soluble polysaccharide called “phytglycogen.” As a result, the dry, sugary kernels are wrinkled and glassy. The higher content of water-soluble polysaccharide adds a texture quality factor in addition to sweetness. In the U.S., sweet corn is eaten in the immature milk stage and is one of the most popular vegetables.

Sweet corn in the U.S. is more important economically than its limited commercial production would indicate, because it is consumed directly as human food (fresh market or canned and frozen products) rather than indirectly as livestock feed. The bulk of sweet corn production is confined to the northern tier of states and to southern Florida as a winter crop.

In the broader sense, vegetable corns include all corn harvested and eaten while the kernels are still tender and before all of the sugars are converted to starch. This definition includes “roasting ears” of selected field corns.

Today, the standard sugary corns are being modified with other endosperm genes and gene combinations that control sweetness to develop new cultivars. As a result, growers must consider genetic type when making selections for planting. The genetic type is not

readily identifiable by cultivar name alone. At least 13 endosperm mutants, in combination with sugary, have been studied for improving sweet corn. Except for sugary, the genes used in breeding act differently to produce the taste and texture deemed desirable for sweet corn.

Augmented sugary kernel types. In these sweet corns, the sugars are modified (increased) by the action of other genes, either partially or completely.

Major modifier genes of kernel sweetness are shrunken-2 (*sh2*) and sugary enhancer (*se*). In partial modifications, the sugary (*su*) kernels are modified by the segregation of major modifier genes such that about 25 percent of the kernels are double-mutant endosperm types possessing the enhanced benefits of the modifier. The addition of the sugary enhancer (*se*) gene along with one of the major modifier genes (e.g., *sh2*) will further modify some of the sugary kernels to about 44 percent double-mutant endosperm types rather than 25 percent.

In complete (100 percent) modification, the sugary (*su*) kernels are all modified with the sugary enhancer (*se*) gene to produce the double combination (*su se*) for obtaining maximum benefit from the *se* gene. Other major modifier genes of kernel sweetness are: brittle (*bt*), brittle-2 (*bt2*), shrunken (*sh*) and shrunken-4 (*Sh4*). Other genes with minor modifying effects of kernel sweetness are: dull (*du*), floury (*fl*), floury-2 (*fl2*) opaque (*o*), opaque-2 (*o2*), sugary-2 (*su2*), and waxy (*wx*). Some are known to be present in sweet corn backgrounds either in the segregating or homozygous state.

Other mutants producing sugary kernels include the single-mutant endosperm genes shrunken-2 (*sh2*), brittle (*bt*) and brittle-2 (*bt2*), and the multiple-mutant endosperm genes amylose-extender, dull, waxy (*ae du wx*).

Precautions with modified endosperm sweet corn to avoid xenia. Isolation of “sweet corn” cultivar plantings of different genetic types is necessary to prevent cross-pollination. Xenia is the immediate effect of foreign pollen on a variety; on sweet corn (*su*), it will produce a starchy kernel. Isolation can be obtained by planting at a different time, planting cultivars of different maturities, planting “upwind” of prevailing wind direction, or providing barriers and border rows. All of these methods will reduce the isolation distances necessary. On a practical basis, commercial growers should provide at least 50 feet separation, plant upwind of normal field corn, and use four or more border rows.

Popcorn

Popcorns are perhaps the most primitive of the surviving races of maize. This corn type is characterized by a very hard, corneous endosperm containing only a small portion of soft starch. Popcorns are essentially small-kerneled flint types. The kernels may be either pointed (rice-like) or round (pearl-like). Some of the more recently developed popcorns have thick pericarps (seed coats), while some primitive semi-popcorns, such as the Argentine popcorns, have thin pericarps.

Popcorn is a relatively minor crop compared to dent corn. It is used primarily for human consumption as freshly popped corn or as the basis of popcorn confections. Isolated planting is not necessary, since there are no major xenia effects on popping expansion and many popcorns are cross-sterile with field corn.

Most popcorn acreage is grown under contract. Although conditions for growing popcorn are the same as for dent corn, special harvesting, drying and storage practices are necessary to maintain popping quality.

Pod Corn

Pod corn (tunicate maize) is more of an ornamental type. The major gene involved (*Tu*) produces long glumes enclosing each kernel individually, such as occurs in many other grasses. The ear is also enclosed in husks, as with other types of corn.

Homozygous pod corn usually is highly self-sterile, and the ordinary type of pod corn is heterozygous. Pod corn may be dent, sweet, waxy, pop, flint or floury in endosperm characteristics. It is merely a curiosity and is not grown commercially.

Special-Purpose Corns

Corn may be altered by genetic means to produce modifications in starch, protein, oil and other properties. As a result of modifications of ordinary dent types, new corn specialties have been created. Among them are waxy-maize, amylo maize, and high-lysine or modified-protein corn.

Waxy corn. This special-purpose type was introduced to the U.S. from China in 1908. Although China was the original source, waxy (*wx*) mutations have since been found in American dent strains. Its name derives from the waxy appearance of the endosperm exposed in a cleanly cut cross-section. Common corn starch is approximately 73 percent amylopectin and 27 percent amylose, whereas waxy starch is composed entirely of amylopectin, which is the branched molecular form. Ordinary cornstarch stains blue with 2 percent potassium iodide solution, whereas waxy cornstarch stains a reddish brown. The waxy gene also expresses itself in the pollen with this staining reaction, which is an aid in breeding.

Significant advances in yields have been made with the newer waxy hybrids. While the overall average may run somewhat less than dent corn hybrids, the newer waxy hybrids are more comparable to the better dents in yields.

Waxy corn has carved out a formidable position as the raw material of waxy cornstarch produced by certain wet-corn millers in the U.S., Canada, Europe, etc., for industry and food uses. Waxy starch and modified waxy starches are sold extensively worldwide because of their stability and other properties of their solutions.

Products made from waxy corn are used by the food industry as stabilizers and thickeners for puddings,

pie fillings, sauces, gravies, retorted foods, salad dressings, etc. Other waxy products are used as re-moistening adhesives in the manufacture of gummed tape, in adhesives and in the paper industry. Waxy grain is also grown as a feed for dairy cattle and livestock.

Waxy corn is usually grown under contract for the major wet millers and exporters. Premiums are paid to the growers of waxy corn for wet milling because it must be isolated during production, harvesting, transporting and storing. Since waxy is a recessive characteristic, isolation from dent corn is necessary to prevent loss of its peculiar starch properties.

High-amylose corn. Amylo maize is the generic name for corn that has an amylose content higher than 50 percent. The endosperm mutant amylose extender (*ae*) found by R. P. Bear in 1950, increases the amylose content of the endosperm to about 60 percent in many dent backgrounds. Modifying factors alter the amylose contents as well as desirable agronomic characteristics of the grain. The amylose-extender gene expression is characterized by a tarnished, translucent, sometimes semi-full kernel appearance.

High-amylose grain is grown exclusively for wet milling. The two types produced commercially are Class V (amylose content, 50-60 percent) and Class VII (amylose content, 70-80 percent). The starch from high-amylose corn is used in the textile industry, in gum candies (where its tendency to form a gel aids production), and as an adhesive in the manufacture of corrugated cardboard.

High-amylose corn yields vary depending upon location, but average only 65-75 percent of that of ordinary dents. Present production acreage is limited to that grown under contract arrangements for wet millers. Premiums are paid to growers because of decreased yields and the necessity to isolate high amylose corn during production, harvesting, transporting and storing. The premium depends upon class, year and desired acreage.

High-lysine corn. This is the generic name for corn having an improved amino acid balance, thus a better protein quality for feeding and food use compared to ordinary dent types. E. T. Mertz in 1964 discovered that the single recessive gene, opaque-2 (*o2*), reduced zein in the endosperm and increased the percent of lysine to improve nutritional quality. Other genes with similar gross effects on protein quality exist in corn, but attempts to improve corn protein quality have been primarily based on use of the opaque-2 gene and modified opaque-2 germplasm.

The opaque-2 gene is characterized by a soft, chalky, non-transparent kernel appearance, having practically no hard vitreous or horny endosperm. Undesirable kernel characteristics (e.g., kernel and ear rots) and insect and rodent damage can be a problem with the soft opaque-2 chalky phenotypes. Improvements in resistance to ear and kernel rots have been substantial

with selection, and a number of good hybrids exist. On the average, the opaque-2 hybrids yield about 7-10 percent lower than their normal counterparts.

A promising approach to overcoming some of the deficiencies of the homozygous opaque-2 materials involves the visual selection of specific modifiers of opaque-2. It is fairly easy to develop modified, vitreous opaque-2 materials with good ear rot and grain insect resistance. Selections must include endosperm chemical analyses to maintain high levels of protein quality.

Another approach to endosperm textural modification to solve some of the problems associated with opaque-2 corn has been use of the double-mutant combination, sugary-2 opaque-2 (*su2 o2*). This modification has improved kernel vitreousness, density and resistance to kernel breakage. The improved vitreous of *su2/o2* is accompanied by protein quality at least equal to the unmodified opaque-2 materials; however, at this point, yields are 80-85 percent of normal dents.

High-lysine grain can be an important source of high-quality protein in the diets of nonruminants; and nutritional studies have confirmed the potential value of high-lysine corn in helping to meet the world's human and animal nutritional needs. For the present, loss of calories per acre is the trade-off for increased amounts of high-quality protein.

Current U.S. use of high-lysine corn is restricted because of (1) yield differentials compared to normal corn and (2) the corn-to-soybean oil/meal price relationship. Demand for high-quality protein corn in the U.S. is insufficient to command a premium price. However, high-lysine corn is grown to a limited extent as a feed for poultry, swine, dairy cattle and other livestock production needs. In corn-dependent countries where normal corn is a major staple of the human diet, or where high-quality protein supplements for animal feeding are scarce, yield is a secondary consideration. Some high-lysine materials are to the point of development where it may be cost-efficient to grow quality-protein corn as a specialty crop.

Ornamental corn. The so-called ornamental or "Indian" corns commonly show segregation for alleles of several genetic factors that control the production of anthocyanins and related pigments in the aleurone, pericarp and plant tissues of corn. The kernels may be segregating for various color expressions; and variegation of color may even be expressed within a kernel, depending upon the genetic factors involved and their interaction during development of the kernel.

Ornamental corns may be dent, sweet, pop, flint or flinty endosperm types. Apart from genetic studies, they are a curiosity and are only grown for ornamental and decorative purposes.

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