Hybrid Seed Production in Corn

(Zea mays L.)

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Corn (maize) is considered the only important cereal crop that evolved in the Americas. Probably originated in Mexico - archaeological evidence of existence 7,000 years ago has been found in Mexico’s valley of Tehuacan. It evolved from teosinte (Zea mexicana). Corn seed production became a major ag industry when realized that hybrid lines could significantly outyield open pollinated lines.

As early as 5,000 B.C., hybrid production of corn was indirectly encouraged by Indian tribes interested in the semi-controlled mixing of endosperm colors during religious ceremonies. These attempts not focused on high yields and it wasn’t until the early 1900’s that breeders developed a method of self-fertilization to select homozygous inbreds. Many deleterious recessive genes were expressed - often resulted in greatly reduced yields while simultaneously encouraging the expression of specific traits.

In 1933, < 1% of corn planted in the U.S. represented hybrids. During this period the development of inbreds, and crossing with other inbreds to produce double-cross hybrids resulted increased grain yields by 10-40% over traditional OP varieties. # of dbl-cross combinations and their superior performance caused rapid adoption of corn hybrids by farmers.

By 1945, approx. 90% of the corn in the U.S. represented hybrids. Today, farmers plant an array of single-cross and modified single-cross hybrids. The success of hybrid corn seed production also spawned a new and vital seed industry. The hybrid corn seed industry in the U.S. currently produces a product valued at over $3.5 billion annually.

U.S. Average Maize Yields 1900 - 2000

Yield trends in the United States have steadily increased since hybrids were first commercialized.
Agricultural Importance

- Worldwide, corn ranks behind only wheat in total production.
- ~ 80% of the corn produced goes to livestock and poultry feed, while ~ 20% is used in food & industrial applications (these values are changing with demand for ethanol, etc).
- In many countries (Africa, Latin America) it is an important crop for food as well as for livestock feed.

Vegetative Development

- Germination of corn seeds is similar to that of many other grasses.
- Germination begins when the seed reaches a moisture content of about 30%.
- Primary radicle is followed by seminal roots as the first organs to emerge from the seed.
- About 12 h later, the coleoptile, which covers the leaves, ruptures the seed coat and is pushed out of the surface by the elongating mesocotyl.

- A normal corn plant develops between 20 and 23 leaves and all are initiated in a growing point that remains below ground until the primordial tassel is formed.
- These events occur during the first 4 weeks of plant development.
- The permanent root system forms in successive whorls from internodes between the first node that develops above the mesocotyl.

Reproductive Development

- Corn is different from other cereal crops because it does not possess a typical grass flower.
- Instead, it produces unisexual flowers on the same plant and is thus, monococious.
- The male flowers are represented by the tassel and the female flowers by the ear.
- Pollen comes from the tassel and the silks are the style of the female flower.

- After tassel initiation, the subsequent vegetative growth of the corn plant is rapid and primarily a consequence of cell elongation.
- It is during this period that a heavy demand for moisture and nutrients occurs.
- Temperature and photoperiod also interact in determining the final height of the plant, which affects yield.

- Development of the reproductive structures begins with tassel initiation below ground.
- Tassel development continues as the vegetative internodes start their rapid elongation and is completed by the time it emerges from the leaf whorl.
- After tassel emergence, pollen shed begins and is completed after 7 to 10 days.
- Pollen dispersal occurs by wind and gravity dissemination.
Ear initials are found on mature plants in axillary buds of lower leaves up to the last axillary bud that produces the ear.

Rapid growth of the ear shoots occurs simultaneously with tassel emergence and the most rapid growth is in the highest position.

Silk elongation is initiated first from ovules at the base of the ear and last from those at the tip of the ear.

Because the tip ear silks appear after basal ear silk emergence, they may not be fertilized if pollen shed has ceased, resulting in a barren tip ear.

Extreme heat or drought also have a much greater effect on the timing of silk emergence than pollen shed or pollen viability, and is linked with poor yields under stress conditions.

After fertilization, seed development begins.

The endosperm first increases in size and is filled with sugars so that the developing seeds resemble watery blisters.

Later the embryo matures using the established endosperm as an energy source.

As the embryo completes its development, the endosperm starts to dry down and sugars rapidly disappear and are replaced by starch.

Dry-down is first at the top or crown of the seed and progresses toward the base.

Seeds at the tip of the cob complete dry-down before those at the base.

Dry-down is marked by the movement of a kernel milk line.

The development of a black layer at the base of the seed signifies the time of physiological maturity, which is considered an indication of seed maturity by grower.

About 800 ovules are produced on a typical ear.

Seed development (L to R: less to more developed). The darker yellow tissue inside the kernel is the embryo.
The seed is botanically classified as a caryopsis because it is a dry (at maturity), indehiscent, single-seeded fruit that includes the tightly fused ovary wall.

- Corn seeds differ dramatically in size and shape.
- Position on the ear is primarily responsible for these differences.
- Large round seeds tend to be at the base of the ear and small round seeds at the tip.

- ~ 75% of corn seeds are between the LR and SR seeds and are flattened due to their tightly packed positions; there is a range in size and shape from large flat (LF) to small flat (SF) seeds.
- Historically, differences in seed size were recognized by the seed corn industry, which marketed according to uniform sizes so that they would fit specific plates found in corn planters.
- Since the early 1970’s the introduction of “plateless” air planters has resulted in equipment that could satisfactorily plant seed regardless of seed size or shape.
- Today, > 85% of seed corn is planted in some areas is with “plateless” planters; there is less need for seed sizing, but it is still a common practice.

- In addition to size and shape differences, the corn endosperm genotype changes the seed appearance and chemistry.
- 5 primary kernel types: dent, flint, floury, sweet corn and popcorn.
- Dent is the most widely grown corn in the U.S., northern Mexico, and southern Canada.
- Believed to have evolved from a cross between flint and a southern white dent (‘Gourdseed’) during the 18th and 19th centuries.

- Dent corn seeds have a vitreous, flinty endosperm at the sides of the kernel and a soft, floury endosperm in the center.
- Its most conspicuous feature is the indentation of the kernel at the crown caused by the collapse of the soft, floury endosperm at the crown of the kernel during dry-down.
Flint corn primarily grown in Europe, Asia, and Central and South America. Kernels are smooth and rounded with no denting and possess a thick, hard, vitreous endosperm surrounding a small granular center.

Floury corn is primarily grown in South America and southern Africa. One of the oldest types and possesses a soft endosperm with no denting. This corn is often ground to produce flour for cooking.

Sweet corn is grown for direct human consumption, and differs from dent corn by only 1 recessive gene that prevents the conversion of sucrose to starch in the kernels.

Popcorn is a small flint type that possesses a hard, vitreous endosperm that explodes when between 13 and 15% moisture content after heating.

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Seed

- Corn seeds differ in color from white to yellow, orange, red, purple and black.
- Different colors attributed to genetic differences in pericarp, aleurone layer, embryo (germ) or endosperm tissues.
- Mature corn seed has three main parts: seed coat or pericarp, endosperm and embryo which is often called the germ.

Pericarp protects seed from invasion by pathogens, minimizes mechanical injury and delays water uptake so that imbibitional injury is reduced.

Endosperm represents ~ 75% of field corn seed dry weight and is the main energy storage area possessing high quantities of starch.

The embryo is composed of two main parts:

- **Scutellum** makes up 10-12% of seed dry wt and believed to be the singular cotyledon. Oil concentration is high (35-40%).
- **Embryonic axis**, consisting of the plumule that already contains the first 5 seedling leaves and the radicle that produces the first seedling roots.

Corn seeds also have a black layer at the base of the seed. The layer forms at physiological maturity at about 30-38% moisture content and is an indication of maximum seed dry wt.
**Composition as Percentages of Whole and Fractionated Corn Kernels.**

<table>
<thead>
<tr>
<th>Fraction</th>
<th>Kernel Starch Sugar Protein Oil</th>
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<tbody>
<tr>
<td>Kernel</td>
<td>100.0 71.5 2.0 10.3 4.8</td>
</tr>
<tr>
<td>Endosperm¹</td>
<td>81.9 86.4 0.6 9.4 0.8</td>
</tr>
<tr>
<td>Germ</td>
<td>11.9 8.2 10.8 18.8 34.5</td>
</tr>
<tr>
<td>Bran</td>
<td>5.3 7.3 0.3 3.7 1.0</td>
</tr>
</tbody>
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1. Composed of starchy and aleurone fractions.

**Seed Production**

- Corn is a warm-season crop.
- Breeders have developed lines that can grow in almost any climate, but corn typically grows best when average temps of 21-32°C (70-90°F) and 15-20 cm (6-8 in) rainfall are encountered for 3-4 consecutive months.
- These conditions abound in the US corn belt, Iowa, Nebraska, Indiana and Illinois are the center of this region.
- Major corn seed companies are located in these states.
- Agronomic practices for the production of seed corn are the same as those for grain except that some additional requirements exist.

**Isolation**

- Corn seed is almost always a hybrid between two inbred parents; first decision in seed corn production is isolation of the seed field.
- Corn is cross pollinated by wind; studies have shown that the greatest “contamination” by pollen occurs 50-75 m (164-246 ft) from the pollinating parent.
- Seed fields are isolated by at least 200 m (656 ft) from other corn.

**Other factors to help in isolating seed corn fields**

- Production in large fields and use of border rows that have a time of nicking (simultaneous pollen release and silk emergence) different from other corn lines reduces the need for as much isolation.
- Location of fields with natural barriers such as hills or trees or that are in a different prevailing wind direction from contaminating fields.

**Quality assurance (QA) specialists from seed companies constantly monitor production fields to ensure that only hybrid seed is produced and marketed.**
- Field inspections provide one measure of this success.
- Many companies have adopted lab electrophoresis programs that evaluate seed protein banding patterns on starch gels for genetic purity determinations.
Identity Preserved (I.P.) Production

- Some growers may choose to preserve the identity of their non-genetically enhanced corn to minimize the potential for movement of pollen from fields containing any genetically improved traits or any such traits not yet approved for export markets (such as the European Union).
- Accepted practice with I.P. production is that each grower has responsibility to provide any necessary crop isolation that might be required.

- Due to unavoidable pollen movement that occurs when producing an I.P. crop, markets have established standards or tolerances.
  - Tolerances are usually small percentages that can be met with reasonable management and production practices.
  - Growers certifying I.P. accept responsibility for the isolation and production practices, identity preservation and ultimately the purity of their crop.
  - Since some buyers of I.P. production have tolerances, contact your grain purchaser relative to their specific requirements.

Tillage

- Minimum tillage used on soils that are poorly drained or where corn is grown on slopes.
- Operations leave the previous crop stubble which reduces soil erosion.
- Disadvantages: cooler, wetter soils at planting and greater dependence on pesticides.

Conventional tillage still practiced in some locations

- Seedbed prep in the fall with a moldboard plow.
- Heavy stubble from the previous crop is turned over and degraded while controlling late-growing perennial weeds; permits turned soil to break down so that secondary tillage in the spring is less extensive.

Planting

- Begin when soil temp is 10C (50F) at a 5 cm (2 in) depth.
- Most plant seed from 2-7 cm deep depending on moisture status of soil; plant deeper for drier soils.
- Seeding rates vary, dependent on row widths and distances between plants.
- Optimum populations of modern hybrids approach 54,000 to 64,000 plants/ha (22,000 to 26,000 plants/A) with 75 cm (29.5 in) row width.
Planting pattern varies, but most common is 1 row of male parent to 4 rows female parent. Selection of parents must be planned so that the male sheds pollen at the time of silk emergence from the female (nicking). A method to ensure successful nicking with differing maturities is the use of split planting dates. Female planted on a different date than male so that synchronous flowering occurs.

Other ways to make minor (3-6 d) adjustments in pollen shed: use variable fertilizer rates, growth regulators to stimulate or retard development, retarding growth via clipping or flaming of one parent, planting at differing soil depths, seed coatings.

Nutrient Management
- Because corn inbreds have poorer rooting ability than hybrids, soil fertility deficiencies may have a great impact on inbred development
- Inbred lines grow best on well-drained, loamy soils with pH from 5.5-8.0.
- Because of rapid vegetative growth, heavy emphasis is placed on appropriate soil fertility

Fertilizers that supply more than 100 kg N, 25 kg P, and 50 kg K/ha are not uncommon to obtain the highest yields. Most important of these is N; can be applied in various forms to minimize nitrification and denitrification. Phosphorus is often applied as a superphosphate or ammonium phosphate. Potassium usually supplied as potassium chloride.

Weed & Pest Control
- Mechanical and chemical control of weeds is used in corn production because of the less competitive ability of inbreds compared to hybrids.
- Early control of annual and perennial weeds is often accomplished using a rotary hoe and rotary cultivator which disrupts the soil and weed seedlings before corn seedlings are established.
- Chemical control used both preplant and postemergence for later control of broadleaf weeds.
- Major weeds of corn: lambsquarters, pigweed, Canada thistle, morningglory, panicum, foxtail and switchgrass.

Corn is also susceptible to a host of diseases and insects.
- Seed-borne fungi include species from the genera Gibberella, Pythium, Fusarium, Drechslera, Diplodia and Helminthosporium.
- Root worm, earworms, grasshoppers, corn borers, and aphids attack vegetative and reproductive structures of corn plant and must be controlled by appropriate insecticides.
Flowering

- Hybrid seed production requires the female parent have its tassels removed or made infertile before its silk emergence to avoid self-fertilization.
- 3 ways to do this:
  1. Manually or mechanically remove tassel - must be done in 7-10 d between when tassel is ready to emerge and pollination. Fields inspected to ensure that no tassels were missed. Yield reductions of up to 10% due to detasseling. Yield reductions even greater with mechanical removal.
  2. Use of parents that possess cytoplasmic male sterility (CMS): incorporation of specific recessive genes into inbred parents that make pollen either sterile or delay pollen shed until well after silks of female parent have been fertilized by desired pollen. Use of CMS narrows the genetic base and makes crop more susceptible to disease.
  3. Use of chemicals to control pollen formation or viability

Male gametocides to control pollen viability or production continue to be explored, along with other techniques for flowering control
- Such methods eliminate the costly need for physical removal of the tassel
- No chemical or alternative means have yet been found as a practical alternative to mechanical detasseling, however, studies are continuing.

Harvesting

- Corn harvested by a picker, a picker-sheller, or a corn combine
- Picker removes ear from stalk, removes husks, and places ear with attached kernels in a wagon
- A picker-sheller provides the same operation and adds the step of shelling or removing the seeds from the ear.
- A corn combine places all operations in one piece of equipment.
Most harvesting of corn for grain is with a combine; for seed use, it is best to retain the kernels on the cob and allow seed to dry further so that mechanical damage is minimized.

Seed should not be harvested at moisture contents above 35-38% so it can be safely dried.

Major risk to seed quality is the possibility of freezes, which reduce germination.

Level of freeze damage is dependent on temp, developmental stage (moisture content), genotype, and husk protection.

Drying

Because seed corn is usually harvested on the ear and at high moisture content, it is necessary to reduce seed moisture content for safe storage.

Usually done by squirrel-cage or fan systems to draw fresh air through a burner and force the heated air through bins filled with seed on the ear.

Heated air can be used but should not exceed 46°C (115°F)

High-moisture seeds more prone to heat injury than low-moisture seeds

If seeds at high-moisture content, drying should begin at a low temp such as 35°C (95°F) until moisture content is 20%, then increase temp to 46°C/115°F.

Seeds typically dried to 12-13% moisture content; the seeds are easily shelled without damage and allowed to dry further in open storage or bins.

Storage

Seeds at 15% moisture can be stored for one season, at 10-12% for 3 seasons, and 8-10% for long-term storage at or below 10°C/50°F.

Low-moisture levels are difficult to handle without incurring additional seed damage.

Conditioning

Begins with shelling the seed.

Shellers essentially rub the seed from the cob.

Once shelled, it is conveyed by belts to the conditioning equipment.

Low-moisture seeds also prone to imbibitional damage following planting.
3 Operations in Conditioning Seed

1. **Scalping operation** – using scalpers or air-screen cleaners to remove cob and kernels, husks, silks and other debris.
2. **Sizing operation** – separates seeds into uniform lots of size and shapes (width, thickness, length); width graders and aspirators used.
3. **Treating seed** - with a fungicide-insecticide slurry prior to bagging.

Most seed corn is now marketed according to size in bagged units of 22.7 kg (50 lb) each or providing bags with 80,000 seeds each which vary in weight from 13.6 to 231.7 kg (30 to 70 lb) because of the differences in seed size.

Quality Control (Role of Vigor Testing)

- Seed corn routinely monitored for germination and vigor to ensure seeds will germinate and produce seedlings under typical production environments.
- Most popular vigor test is the cold test, which mimics early spring planting conditions by stressing seeds under cold, wet conditions and determining their emergence capability.
- This test is so important that most seed corn contracts in the U.S. corn belt provide stipulations that the seed must meet a minimum 92/82 standard: 92% germination and 82% cold test.

Types of Hybrids-Advantages & Disadvantages

**Inbred Lines:**
- True breeding (homozygous) parents for hybrid corn
- Developed by corn breeders using artificial self-pollinating (inbreeding) accompanied by vigorous selection for desired characteristics for 5 or more generations.
- Seed producer can duplicate the exact characteristics of a particular hybrid each time a seed crop is produced.

**Double-Cross Hybrids:**
- First successful commercial hybrid seed corn
- Produced by crossing two different single crosses, giving the pedigree [(AxB)x(CxD)]
- This permitted four different unrelated inbred parents with desirable characteristics to be brought together into one hybrid.

Seed yields on inbred plants are low [672-2,688 kg/ha (10-40 bu/A)] since inbreeding results in a marked decrease in vigor and productivity.

Hybrid vigor (heterosis) occurs when two highly selected unrelated inbreds possessing desirable characteristics are crossed.
Double-crosses were necessary because the first inbred lines had poor vigor and performed poorly as female parents.

Thus, single cross hybrids had to be formed because they had enough vigor to enable them to be good female parents.

This allowed hybrid seed production to be a practical, economical system that produced adequate seed that could perform well for farmers.

Double-cross plants are more variable than single or 3-way crosses.

They are not all alike genetically and allow breeders to bring more different desirable characteristics together into one hybrid than is possible in a single cross.

The plants may be “buffered” more against unfavorable situations, which frequently occur at one or more times during the growing season.

Double-cross plants also have a longer pollination period, which tends to provide more complete filling of the ear with seed, often resulting in higher yields.

Lower seed costs are an obvious advantage where the yield of the double-crosses are equal or better than the best single-crosses.

However, fields of double-cross hybrids do not possess the “eye appeal” of single-cross hybrids because the plants and ears tend to be more variable.

May be more difficult to obtain a high level of disease and insect resistance in double-crosses compared to single-crosses.

Double-cross hybrids may not take full advantage of highly favorable environments as a well adapted single-cross.

Single-Cross Hybrids:

- Most modern commercial hybrid seed
- These are crosses between two inbred lines.
- Now practical because modern inbred lines have been developed with adequate plant vigor to make good (productive) female parents.

A field planted with single-cross seed is impressive because plant height, ear height, tasseling, silking, pollen shedding and all other characteristics are extremely uniform.

Because of the availability of excellent inbred female parents, single-cross hybrids represent almost 90% of hybrid corn seed market.
Genetic uniformity of single-cross plants offers a particular advantage for high-yield environments, where they yield better than the best double-crosses.

- Only two inbred parents are involved, a higher level of resistance to diseases, insects and unfavorable weather is evident.
- If any component is adverse, it will affect all of the single-cross plants, resulting in lower performance.
- Pollen shed occurs during a shorter period since all the plants are genetically alike, with the potential for lower yields, especially under stress conditions.

Three-Way Hybrids

- Crosses can be made between a single-cross hybrid (AxB), as the seed parent with an inbred line, C, as the pollen parent to give the pedigree [(AxB)xC].
- Three-way hybrid seed is produced on single-cross plants so that yield and quality may be equal, or nearly so, to double-cross seed.
- The pollinator is an inbred parent, and this may add some cost to seed production.
- More variable than single-crosses and less variable than double-crosses.
- Advantages and disadvantages are likely to be between those double and single crosses.

Three-way crosses generally used for commercial popcorn production since they produce more uniform quality (e.g., popping expansion, pericarp thickness) than double-crosses.

- They are also commonly used for commercial sweet corn production since complete uniformity is desired for timely harvest and for uniform canning and table quality.

Sweet corn seed production

<table>
<thead>
<tr>
<th></th>
<th># kernels/lb</th>
<th>kernels/kg</th>
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</thead>
<tbody>
<tr>
<td>normal sugary (su)</td>
<td>2,500</td>
<td>5,500</td>
</tr>
<tr>
<td>sugar enhanced (se)</td>
<td>3,500</td>
<td>7,700</td>
</tr>
<tr>
<td>supersweet (sh2)</td>
<td>3,800</td>
<td>8,400</td>
</tr>
<tr>
<td>triple sweets (su se sh2)</td>
<td>6,500</td>
<td>14,300</td>
</tr>
<tr>
<td>field corn (Su)</td>
<td>1,800</td>
<td>3,960</td>
</tr>
</tbody>
</table>

(Marshall & Tracy, 2003)

Harvesting high-sugar sweet corn

- Commonly harvested at 50-55% SMC, vs. ~30% for su1 seed
- Modified pickers used, and ears with husks are delivered to conditioning plant
- Modified husking beds (24º angle vs. 18º, plus alternating rubber and steel rollers) to minimize pericarp damage

(Marshall & Tracy, 2003)

Conditioning high-sugar sweet corn

- Slower moisture loss than su1 seed
- Drying ears takes longer (more expensive)
- Drying temps usually less than 98°F (37°C)
- Drying rate should be as rapid as possible, use larger volumes of air thru dryers

(Marshall & Tracy, 2003)
Conditioning (continued)

• Shelling, milling, sizing, sorting, treating and packaging processes again modified for high-sugar sweet corn seed.
• Electronic sorters remove discolored kernels
• Milling, sizing equipment modified to handle seed ½ the weight and size of su1
  
  (Marshall & Tracy, 2003)

Kernel properties associated with poor sweet corn emergence and seedling vigor

• Seed maturity at harvest
• Pericarp injury and other damage during harvest, drying
• Membrane damage due to rapid imbibition
• Solute leakage during germination

Summary – hybrids, blends, etc.

• Hybrid: 1st generation cross between one or more inbred lines as described below. Hybrids do not qualify as varieties, since they are not genetically stable, i.e., they lose hybrid vigor if replanted, and because of segregation and uncontrolled crossing, establish new genetic combinations.
• Inbred line: homozygous true breeding strain of corn maintained by self-or sib-pollination

• Single-cross hybrid: the 1st generation of a cross between 2 inbred lines
• Three-way hybrid: the 1st generation of a cross between two single-cross hybrids.
• Multiple-cross hybrid: the 1st generation of a cross involving more than four inbred lines, i.e., a cross of two double crosses, a single-cross hybrid crossed with a double-cross hybrid, etc.

• Synthetic: advanced generation of a hybrid maintained in isolation with open pollination.
• Blend: a mechanical mixture of 2 or more varieties, hybrids, strains, etc.
• Open pollinated variety: advanced generation of an intercrossing population of multiple genotypes maintained in isolation
Credits

- McDonald and Copeland: Seed Production text
- ISU Report No. 48