A Journey of Hybrids in Maize: An Overview

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ABSTRACT
The increased size and vigor of hybrids between plant varieties and species had been known for centuries. The transition from open-pollinated to hybrid maize was astonishingly rapid. The greater uniformity of hybrids was useful for mechanized harvesting, and this was undoubtedly a factor for rapid transition. The hybrids could also incorporate favorable qualitative traits and be adapted to different habitats, especially length of growing season. The hybrids in maize were introduced through two-way crosses and four-way crosses. The next major change came with the increasing practicality of single cross hybrids. Eventually, in the 1960s, single crosses began replacing double crosses. Not only were the single crosses higher yielding than double crosses, but they were even more uniform. With the coming of single crosses, not only did the yield show a sudden increase, but the rate of increase improved. After single-crosses predominated, the annual increase was almost 2 quintals per acre. This was American scenario, whereas in India the maize hybrids were introduced as early as 1940 with development and release of first Indian hybrids, i.e., VL Makka hybrid 42 from VPKAS, Almora. All the inbred included the American materials. It took almost three and half decades in India to have its first single cross hybrid. This was due to the fact that we always had shortage of inbreds in early maturity group.

Key words: Hybrids, Maize, Nicking, Single Cross, Double Cross

American Hybrids: Maize is a tropical plant, was first domesticated about 8,000 years ago in Central America. Many different types of maize evolved with the effort of indigenous people who were the first maize breeders. The development of a new maize hybrid is a slow and costly process. New hybrids must possess improved yield, stand ability, resistance to pest and tolerance to various stresses. This means that the coordinated expertise of breeders, entomologists, pathologists, physiologists and many other specialists are required. Maize grain yields have increased in North America from approximately 1.3 t/ha in 1930 to 8.7 t/ha in 1994 or approximately 0.08-0.1 t/ha per year. This steady increase is due to a combination of improved hybrids, increased use of fertilizers, better weed control and higher plant densities. The increased size and vigor of hybrids between plant varieties and species had been known for centuries. Shull (1908) reported that inbred lines of maize showed general deterioration in yield and vigor, but that hybrids between two inbreds immediately and completely recovered. In many cases yield of hybrids exceeded that of the varieties from which the inbreds were derived. Furthermore, hybrids had a highly desirable uniformity. The word “heterosis” was introduced by Shull in 1914 as shorthand for such awkward expressions as “stimulation of heterozygosis”. He emphasized that the word was not intended to imply any particular explanation, but was purely descriptive. Meanwhile back in the maize belt, selection for improved yield in open-pollinated varieties was proving to be ineffective. Although qualitative traits could be readily improved by selection, yield was not very responsive. Shull’s idea of crossing inbred lines spread rapidly through the agricultural experiment stations in the 1920s, stimulated especially by Jones’ idea of four-way crosses. In 1924, Henry A. Wallace, sold a few quintals of seed from his recently developed hybrid crosses, the first commercial sale of hybrid seed (Crabb, 1947). Several companies appeared in the next decade. In some regions the inbred lines and crosses were performed by companies who sold the seed each year to farmers. The transition from open-pollinated to hybrid maize was astonishingly rapid. In Iowa, the proportion of hybrid maize grew from less than 10% in 1935 to well over 90% a decade later. In the southern United States, the transition was more gradual and took place over a period of about 20 years. The transition in the Midwest was even slower, occurring over a period of about 30 years.
4 years later. But by the 1950s, the great bulk of maize throughout the United States was hybrid. The greater uniformity of hybrids was useful for mechanized harvesting and this was undoubtedly a factor for rapid transition. Furthermore, a field of maize in which all the plants are alike, each with a single ear at the same height, is aesthetically pleasing and this appealed to many maize growers. The hybrids could also incorporate favorable qualitative traits and be adapted to different habitats, especially length of growing season. Selection for high-performing hybrids was a vast undertaking involving an enormous number of tests. Inbreds were poor predictors of hybrid performance, and two-way crosses, of four-way yields. Testing of a large number of four-way crosses was a tremendous job, since there were six possible single crosses among the four strains used to produce a double cross. One useful device was due to M. T. Jenkins (Crabb 1947). He suggested predicting four-way yields by the average of the four crosses other than the two used to produce the single crosses. The next major change came with the increasing practicality of single cross hybrids. Eventually, in the 1960s, single crosses began replacing double crosses. Selection for higher yield in inbred lines had produced inbreds with yields high enough that they could be used as seed producers. In fact, the inbred lines were as high-yielding as the hybrids of an earlier period. But the single-cross hybrids were better still, and the gap between inbreds and hybrids remained. Not only were the single crosses higher yielding than double crosses, but they were even more uniform. With the coming of single crosses, not only did the yield show a sudden increase, but the rate of increase improved. Before the introduction of hybrids in the 1930s, there was almost no increase. In the double-cross era, the rate of increase was about 1 quintal per acre per year. After single-crosses predominated, the annual increase was almost 2 quinlants per acre. Current yields are some five times what they were in the pre hybrid days. Furthermore, there appears to be no reduction in the rate of increase, so there is no reason to expect that the yield will plateau in the foreseeable future. Single Cross Hybrid technology has been widely adopted because of its high yield, uniformity, easy production methods, ability to withstand biotic and abiotic stresses and food and nutritional security.

Indian Journey: Currently in India, the crop is grown on area of 9.4 million ha with production of 23.00 million tons having an average productivity of more than 2.4 tons/ha, contributing about 9% to the Indian food basket. The success story of single cross hybrid in US Corn belt is well known. Its impact has been realized in China, Brazil, Canada and many other countries too. With the adoption of single cross hybrid technology in 1960s USA productivity increased 3.5 tons/ha (1960) to 9.68 tons/ha (2008). The annual increase in productivity with 100% coverage under Double cross hybrid was only 60kg/annum in 25 years and with Single cross hybrid cultivation the productivity per annum is more than double in a period of 50 years. Parallel to USA in India the productivity remained less than 1 ton/ha for many decades. After shifting to Single Cross Hybrid Technology (2006-2008), in India has witnessed 30% increase in production and 27% increase in productivity within two years with the coverage of 20% area under Single Cross Hybrid. There is also 15% annual increase in production and more than 12% increase in productivity. India became net importer to potential exporter. This is the visible impact of single cross hybrid technology. Maize breeding in India has gone through many phases since the inception of AICRP on maize in 1957. However, the year 1988-89 has been a threshold year with the launching of Single Cross Hybrid (SCH) breeding program and adoption of New Seed Policy. SCH breeding activities witnessed many positive changes and accomplishments in generating vital scientific information as well as commercial products. Now research efforts have been focused on the development of high yielding single cross hybrids for different agro-ecological regions of the country seeing the strength of heterosis for high yield and tackling the problems posed by biotic and abiotic stresses. This has been duly supported by development of vigorous genetically diverse inbred lines that have good performance per se as well as in cross combinations.

**WHY HYBRID MAIZE**

When maize is self-pollinated, each generation becomes weaker. Self-pollination is the process of taking the pollen from a single plant and applying this to the silks of the same plant. This is called inbreeding, and after successive generations leads to weakened plants called inbred lines. These inbred lines are small in size, have small cobs and reduced yields. However, when two inbred lines are crossed, the vigour is restored in the resulting seed, and the yield of the plants grown from the seed is greatly increased. This is called hybrid
vigour. It occurs as a result of the interaction between the sets of genes obtained from the two different inbred lines. The effect of some of the harmful genes expressed in one of the inbred lines will be masked by more beneficial ones found in the other parent plant. This is called heterosis and has been exploited to develop hybrid cultivars that are now widely grown by farmers.

The advantages of growing hybrid maize:

1. Hybrids are generally higher yielding than open-pollinated varieties, if grown under suitable conditions.
2. Hybrids are uniform in colour, maturity, and other plant characteristics, which enables farmer to carry out certain operations, such as harvesting at the same time.
3. The uniformity of the grain harvested from hybrids can also have marketing advantages when sold to buyers with strict quality standards.

The disadvantages of growing hybrid maize

1. Hybrid seed is more expensive than open-pollinated maize seed.
2. The farmer needs to have more than 2 t/ha in order to justify the cost of the seed. Farmers situated in a low potential environment and who cannot afford extra inputs such as fertilizer, will not recover the costs of the hybrid seed.
3. Fresh hybrid seed needs to be bought every planting season. The grain from a crop grown with hybrid seed should not be used for seed. The farmer cannot replant grain as seed without major reductions in yield, which might be a decrease of 30 % or more.
4. The farmer might not always be able to source new seed in time for the planting season.

Different Types of Hybrid in Maize: Crosses between males and females can be made in five different ways to give rise to different kinds of hybrids:

a. Double cross b. Three way cross c. Single cross d. Two parent cross e. Top-cross

a. Double Cross Hybrids: In this cross, both parents are single-cross hybrids. The most prevalent type of hybrid that was grown in the United States in the 1930’s and 1940’s is known as a double-cross hybrid. As the name implies, producing a double-cross hybrid requires two stages of crossing involving two pairs of inbreds. In Step 1, two pairs of inbreds, A and B and C and D, are crossed to produce single-cross hybrids, A × B and C × D. In Step 2, the two single-cross hybrids produced in Step 1 are crossed to produce the double-cross. Typically, A and B are closely related and C and D are also closely related, but neither A nor B is closely related to C or D. Unlike a single-cross hybrid, plants of a double-cross hybrid are not genetically uniform.

b. Three-way Cross Hybrids: Three parents are involved in a three-way cross hybrids. The female of a three-way hybrid is a single-cross hybrid, while the male is an inbred line.

c. Single Cross Hybrids: Two unrelated inbred parents are crossed to produce single cross hybrid. The two parents of a single-cross hybrid, which is also known as a F1 hybrid, are inbreds. Each seed produced from crossing two inbreds has an array (collection) of alleles from each parent. Those two arrays will be different if the inbreds are genetically different, but each seed contains the same female array and the same male array. Thus, all plants of the same single-cross hybrid are genetically identical. At every locus where the two inbred parents possess different alleles, the single-cross hybrid is heterozygous. Plants of a single-cross hybrid are more vigorous than the parental inbred plants. The increase in vigour of a hybrid over its two parents is known as hybrid vigour. If a single-cross hybrid is allowed to open-pollinate, each of the plants grown from the resulting seed will be genetically unique.

d. Two Parent Cross: Non-conventional hybrids have at least one non-inbred parent. Among the several possible non-conventional hybrid combinations, two-parent hybrids that involve one narrow-base seed parent and a male inbred parent in particular, offer great scope for exploitation of heterosis as well as significantly superior seed yield as compared to inbred seed parent. Genetic base of two-parent hybrids is much broader than conventional hybrids and hence are less vulnerable to pest and disease epidemics. Two-parent hybrids provide good short term alternative in the absence of conventional hybrids and are considered viable alternative to single cross hybrids especially in hill and marginal areas wherein the seed production infrastructure is not well developed. The seed parent of two-parent hybrids yield 50-60% more than the female inbred parent of single cross hybrids and also less influenced by environmental fluctuations thus facilitating seed production targets for a specific area in a limited
span of time. Besides, the cost of F1 seed could be reduced to a significant extent due to less number of isolations required during seed production and better seed yields as compared to single cross hybrids.

e. Top-cross: In this case, one of the parents is an open-pollinated variety and the other is a single-cross hybrid.

Steps to Develop Hybrids in Maize: There are five major steps in the development of a commercial maize hybrid:

1. Selection and development of appropriate source germplasm
2. Development of superior inbreds
3. Testing of inbreds in experimental hybrid combinations
4. Identification of a superior hybrid combination
5. Multi-location testing of the pre-commercial hybrid

To understand how a new hybrid is developed, a basic knowledge of maize pollination and breeding processes is required. Hybrid maize is produced by crossing between two unrelated male and female plants of genetically dissimilar inbred parents. By nature of the maize plant having separate male and female flowers, the tassel and cob, it is possible to control the crossing or mating of the plants. A plant may be used as either a male or female parent. If a plant is used as a male, the pollen from the plant is used to cross onto the silks of a different female plant. The pollen from the female plant is eliminated, usually by physically removing the tassel from the female plant before it sheds its pollen. The resulting seed on the female plant gives rise to hybrid plants that are uniform in colour, maturity, plant height and other plant characteristics. In order to produce seed of hybrid maize, the male and female inbred lines are grown under strict conditions and evaluated for yield potential and field characteristics.

Plant breeders carefully select the parents of hybrids over many years of testing. They are chosen based on performance, disease resistance, drought tolerance, and maturation length. Only the best hybrids are released for commercial production and sale. The production of seed is done in a very controlled manner.

Hybrid Seed Production in Maize: Hybrid is produced by crossing between two genetically dissimilar parents. Pollen from male parent (pollen parent) will pollinate, fertilize and set seeds in female (seed parent) to produce F1 hybrid seeds. For production of a hybrid crossing between two parents is important, the crossing process will results in heterosis.

Hybrid seed production is strictly monitored in order to avoid contamination. Male and female parents are inter-planted in alternating rows. There are normally 3 female rows and 1 male row in North India conditions. The female plants are de-tasselled before they shed any pollen, i.e., the tassels are physically removed. Only the male plants will shed pollen in the field. Inspectors check to see that all emerging female tassels are removed and that neighbouring maize plants are at least 400 meters away. This is to ensure that pollen from nearby crops do not fall on to the silks of the female plants. Thus, the female plants are fertilized by pollen that comes only from the male plants. Once the male plants have provided the pollen, they are removed from the field to ensure there is no mixing of seed between the male and female plants. Only the seed from the female plants constitutes the hybrid seed. It is important that the male and female plants flower at the same time and that the pollen is shed from the male plants when the female silks are receptive, in order to produce a maximum amount of seed. This is called nicking. There are three stages in commercial seed production:

The production of the breeder’s seed: This is when the breeder selects and produces the seed for the inbred lines. Only a little seed will be produced as inbred lines are not very vigorous. This seed will then be used for foundation seed production.

The foundation seed is the first multiplication of the breeder’s seed (inbred lines). This is also the stage in which the single-cross hybrid will be produced for the three-way or double-cross hybrids. Enough seed of the parents will be produced in order to produce the hybrid seed.

Certified seed is the last stage in seed multiplication. Seed companies contract approved and capable farmers to plant the foundation seed in the ways described above in order to ensure purity and to produce enough seed for the farming sector.

Certified seeds of parental inbreds are planted in appropriate Male: Female ratio for commercial production of hybrid seed. Throughout the production of hybrid seed, the seed company and the seed producer have to adhere to certification standards. The seed fields are checked for isolation, off-types and purity, while the harvested seed is verified for lack of defects,
adequate germination rate and freedom from pests and diseases. Any crop that fails to meet the standards is rejected and may not be sold as seed. Seed that has been certified by the authorizing agency is labelled accordingly and may be sold. For maintaining genetic purity without isolation distance, seed village concept should be adopted where only one Inbred/ Single cross hybrid seed production taken in one village. Seed village concept also facilitates easy monitoring, reduces the cost of transportation and hybrid seed.

REFERENCES