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8. Breeding Methods in Cross Pollinated Crops

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Abstract:

Breeding methods of cross pollination crop mainly focus on population improvement, large group of intermating individuals is called population. Heterozygous nature of cross-pollinated individual plant is exploited in breeding methods of cross-pollinated crop, to analyses the genetics of a heterozygous mother plant, cross it with known testers, which could be inbred or a related of the mother plant. This gives an estimate of a mother plant's genetic value, also known as combining ability. The ability of an individual to pass on superior performance to its progeny is referred to as combining ability. There are two kinds of combining ability: general and specific. The average or overall performance of a genotype in series of crossings is referred to as general combining ability (GCA). The performance of an individual plant in combination with another individual plant or strain is referred to as specific combining ability (SCA). Improving desired gene frequencies in population is the main objection of breeding in cross pollinated crop by different selection methods, hybrid and synthetic variety development.

Keywords:

Selection, Population Improvement, Progeny Selection, Recurrent Selection, Breeding Methods, Hybrid Development, Synthetic Variety

8.1 Introduction:

Plant breeding is both an art and a science that involves the genetic improvement of crop plants[1]. Generally, cross-pollinated crop populations are genetically variable, exhibiting inbreeding depression, and are highly heterozygous[2]. Breeding methods for cross-pollinated crops are not well defined compared to self-pollinated crops, mainly due to the different population structure.

Species that frequently cross-pollinate experience simultaneous self-pollination and cross-pollination, resulting in homozygosity through self-pollination and heterozygosity through outcrossing.

Therefore, breeding methods depend on the crop's mode of pollination. Selection, introduction, hybridization, and the development of synthetic varieties are different methods used to develop new varieties in cross-pollinated crops[3].

Population improvement and the development of hybrid and synthetic varieties are two breeding methods commonly used for cross-pollinated crops[4] and sometime in self-pollinated crops.

8.2 Population Improvement Methods.

The concept of population development occurs through the repetition of selective mating cycles involving several fertile genotypes, gradually eliminating deleterious and less beneficial alleles.

Population development is a slow, steady, and long-term process. There are two methods of population improvement viz with progeny testing (ear to row methods and recurrent selection) and without progeny testing (Mass selection) [5].

8.2.1 Methods of Breeding without Progeny Testing:

A. Mass Selection:

Mass selection is one of the ancient, easiest, and simplest selection methods based on the phenotype performance of individual plants.

It involves selecting individual plants[6]. Seeds selected from selected plants are planted in large quantities to breed the next generation without testing the offspring.

Large-scale selection for visually measurable high heritability traits, such as flowering time or disease resistance, will alter the seed frequency of good selection [1]Progeny testing is not conducted.

To increase the frequency of favorable alleles, the selection cycle may be repeated one or more times. It is known as phenotypic recurrent selection[2]. Large number of plants is selected to minimized the inbreeding.

The efficiency of mass selection primarily depends on the number of genes controlling the trait, gene frequencies, and, more importantly, the heritability of the specific trait[5].

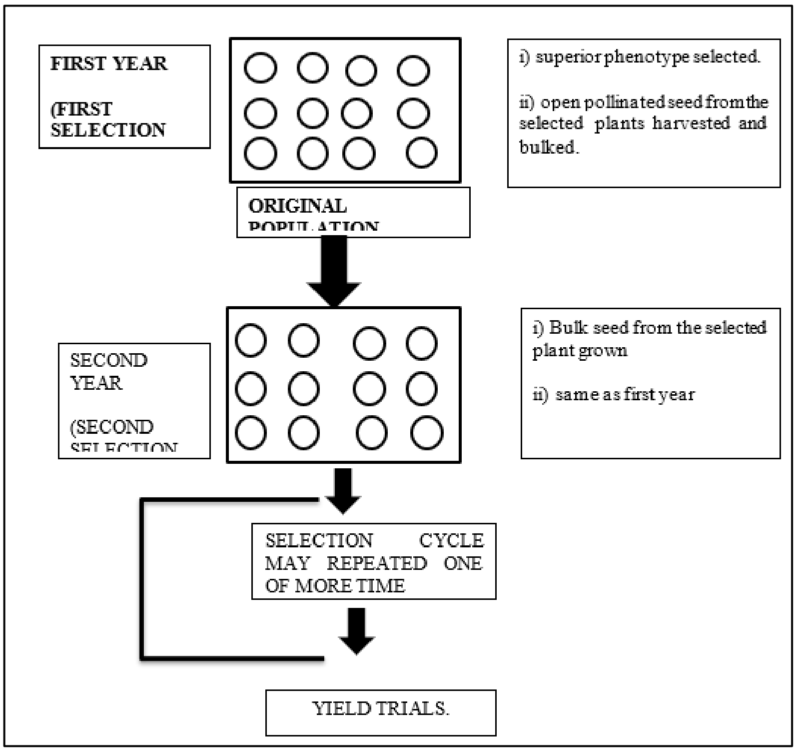

Figure 8.1: General Mass Selection Scheme for Cross Pollinated Crop[5].

a. Merits of Mass Selection:

- Varieties developed exhibit higher adaptability due to genetic variability, providing buffering against abnormal environments.
- Faster release of varieties is achieved.
- The original population's genetic variability is preserved.

b. Demerits of Mass Selection:

- Lack of uniformity compared to pure line varieties.
- Uncertainty arises about the selected plant's superiority, as the absence of progeny testing makes it unclear whether it is due to genotype or environmental factors.
- Difficulty in achieving the same level of uniformity as pure line varieties, making certification challenging[7].

c. Modification of Mass selection:

There are two disadvantages to mass selection:

i. No control over the source of pollen.
ii. The complex connection between the environment and a plant's phenotypic.

Corrective actions such as the following can be made to fix these shortcomings:

- Remove inferior plants from the field and let open pollination occur on the remaining plants. Although this method gives some control over the pollen source, inferior plants are identified only by characteristics expressed prior to flowering.
- To pollinate the plants you have chosen, collect and mix pollen from each of the plants which is selected. This provides full control over the source of pollen.
- Use the 'grid method of mass selection,' or stratified mass selection, as recommended by Gardner in 1961. To do this, the selection field is divided into several small plots, each with 40–50 plants. Rather than selecting between plots, an equal number of superior plants are selected within each plot. In order to create the following generation, the seeds from every plant that was chosen are combined. When compared to the entire field, this stratification decreases environmental variance within the small plots, including changes in soil fertility. As a result, it is anticipated that plot selection will be more successful. Using this method, the yield potential of the open-pollinated Hays Golden maize variety has been successfully increased by about 3% every cycle over a period of 15 generations[5].

8.2.2 Methods of Breeding with Progeny Testing:

A. Ear to Row Method of Selection:

C.G. Hopkins developed ear-to-row method of selection for low and high oil and low and high protein contain in maize[8].The steps of ear to row selection methods is as follows:

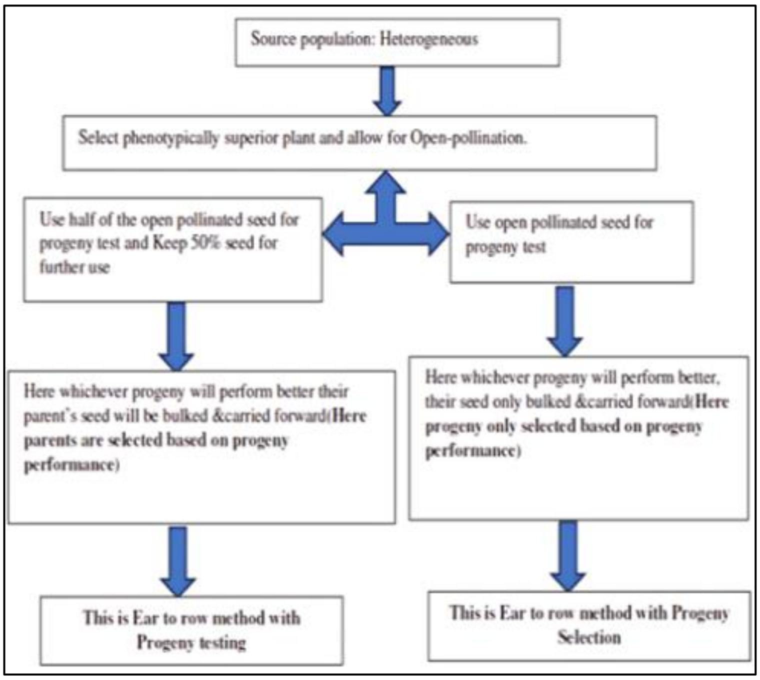

Figure 8.2: Ear to Row Method of Selection[12]

First year: 50-100 superior plants are selected based on phenotype. Open pollination is allowed. Harvest seeds separately from the selected plants.

Second year: Grow progeny rows from each selected plant of 10-15 plants. Identify rows with superior progeny, select the superior plant from the superior progeny based on phenotype, allow open pollination, and harvest seeds from each individually selected plant separately.

Third year: Progeny rows from selected plant is grown and the process of is repeated[5].

Subsequently, some researchers used the method to identify outstanding ears within high-performing families, improving yield of crops and agronomic traits. Unfortunately, a number of experimental limitations, including inbreeding problems and a lack of pollen control, led to disappointing results[9].

a. Modification of Ear to Row Methods:

First year: 50-100 superior plants are selected based on phenotype. Open pollination is allowed. Harvest seeds separately from the selected plants.

Second year: Grow progeny rows from each selected plant of 10-15 plants. Seeds which are remained from the selected plant is kept separately.

Third year: The seed of 1st year plant that produces superior progeny in 2nd year is bulked and planted in third year, open pollination is allowed, this provides selection version of population. Selection cycle can be repeated one or two time.

This modification needs two years to complete one selection cycle while ear to row selection only needs one year to complete one selection cycle[5].

b. Modification of Progeny Selection:

Selfed progeny selection the other term for it is S1 family selection. Selfed seeds are utilized in this approach to test the progeny. If seeds are obtained after two generations of selfing, the process is known as S_2 family selection[5]. Procedures for selfed progeny selection typically result in taller plants[9].

Test cross selection this selection technique is based on combining ability evaluation. Test crosses of S_0 plants or S_1 or S_2 progenies are created and evaluated for performance techniques are described as recurrent selection for general (gca) and specific combining ability$_8$. Common tester is used to obtain the seeds for progeny testing$_5$.

Modified ear to row selection (replicated evaluation) using single replication half sib progeny test is conducted at 3-4 different location, this method is suggested by Lonnquist (1964)[9]. Plant selected from progenies are plant at different yield trail and crossing block, detasselling is done in crossing block progenies and are pollinated by selected plant progenies planted after 2-3 progeny row. On the bases of yield trial superior progeny is selected and their seeds are harvested separately further handled in the same way as normal selection methods.

Main Features of this selection method is in one year each selection cycle is completed, controlled source of pollen, replicated trials are the ways for evaluation of progenies[5].

Full sib progeny test for progeny test seeds is obtained by crossing both the parent in pair so progeny have both the common parent[5].To choose combination with high Vigor in cross pollinated crop this selection method is mostly used[8]. This type of process is also known as full sib family selection.

Merits of Progeny Selection:

i. Because progeny selection is based on progeny performance, it is a reliable strategy for identifying superior traits.

ii. The simplicity and convenience of this procedure identify it.

Demerits of Progeny Selection:

i. The fundamental disadvantage of progeny selection is the inability to control pollination. Superior progeny plants could still be pollinated by inferior progeny plants.

ii. Testing the progeny of each plant in isolation would need a significant amount of room, which is frequently unfeasible[10].

B. Recurrent Selection:

Hayes and Garber in 1919 first suggested the idea of recurrent selection and also by East and Hull in1945 suggested that in improving specific combining ability recurrent selection can be helpful[10]. Jenkins in 1940 described about the selection procedure of recurrent selection. In breeding programs, recurrent selection is a widely used approach for improving populations. In this method of breeding, a group of plants is transmitted to the next generation, so establishing a new cycle of combining. This cyclic process is repeated several times, gaining the term "recurrent selection." The end result is a better population that outperforms the original one in mean performance for the trait(s) of interest, along with increased genetic diversity. Because of the continual process of crossing in recurrent selection, opportunities for genetic recombination are introduced, resulting in greater genetic diversity in the population. This repetitive process also allows for the breakdown of linkages, which increases genetic variety[11]. It involves reselection generation after generation with interbreeding of selected plants. It is also used to established a broad genetic base in a population, effective for those characters that have high heritability, additive gene action can be exploited during this selection. There are four types of recurrent selection schemes: simple recurrent selection, Recurrent selection for specific combining ability (RSSCA), Recurrent selection for general combining ability (RSGCA), reciprocal recurrent selection (RRS).

a. Simple Recurrent Selection:

This method involves the selection and self-pollination of a number of desirable plants, in next season progeny rows from the selected plants is grown, in all possible combination progenies are intercrossed by hand and the mixing of equal amounts of seed from each cross to raise the next generation. It is original selection cycle; several desirable plants are chosen from this and self-pollinated. Intercrosses are made and progeny rows are grown. The same number of seeds are combined to produce the next generation[12].

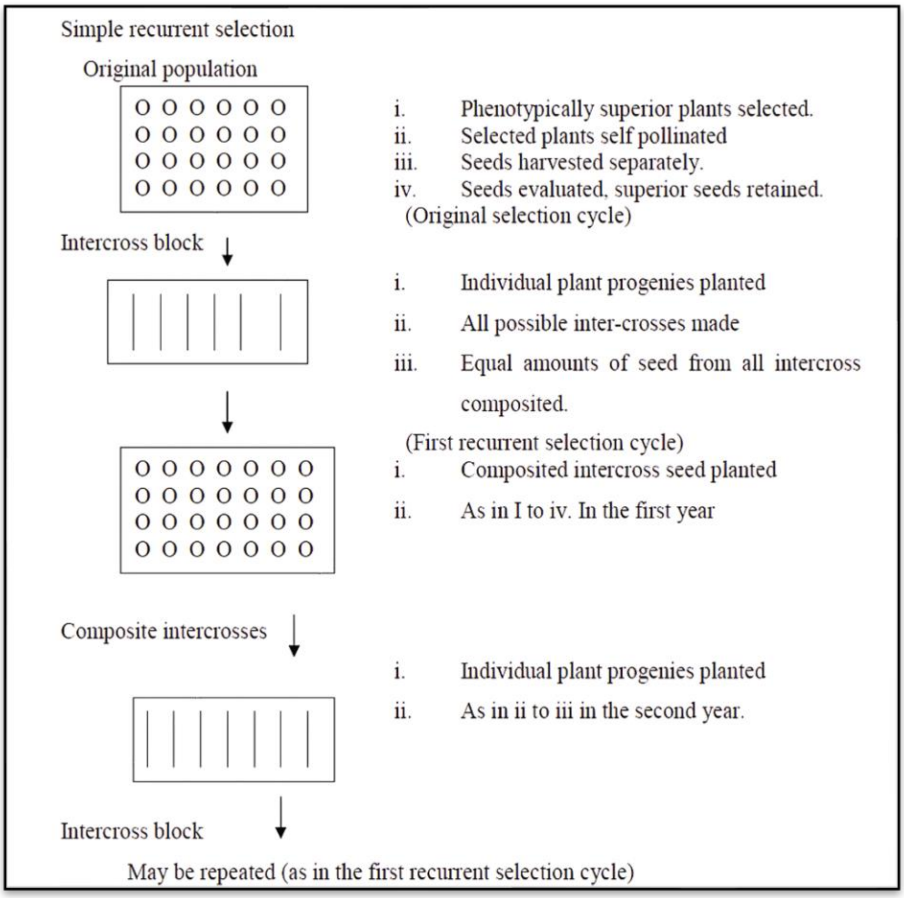

Figure 8.3: Simple Recurrent Selection[6].

Recurrent Selection for General Combining Ability (RSGCA):

The progenies selected for progeny testing are acquired in this case by crossing the selected plants to a tester parent with a broad genetic basis. A tester parent is a common parent that has been mated to several lines. A collection of crossings of this type is used to estimate the combining ability of the selected lines. An open pollinated variety, a synthetic variety, or a segregating generation of a multiple cross is a tester with a large genetic background. This is an expansion of Jenkin's (1940) strategy for short-term synthetics creation[12].

Recurrent Selection for Specific Combining Ability (RSSCA):

In 1945, Hull proposed Recurrent Selection for Specific Combining Ability (RS SCA). The basic purpose of RS SCA is to find and isolate lines from a population that are highly compatible with a given inbred. The basic idea is that non-additive gene activities, such as dominance and epistasis, account for a considerable amount of heterosis. This feature of heterosis, known as Specific Combining Ability (SCA), is dependent on specific gene combinations[5].

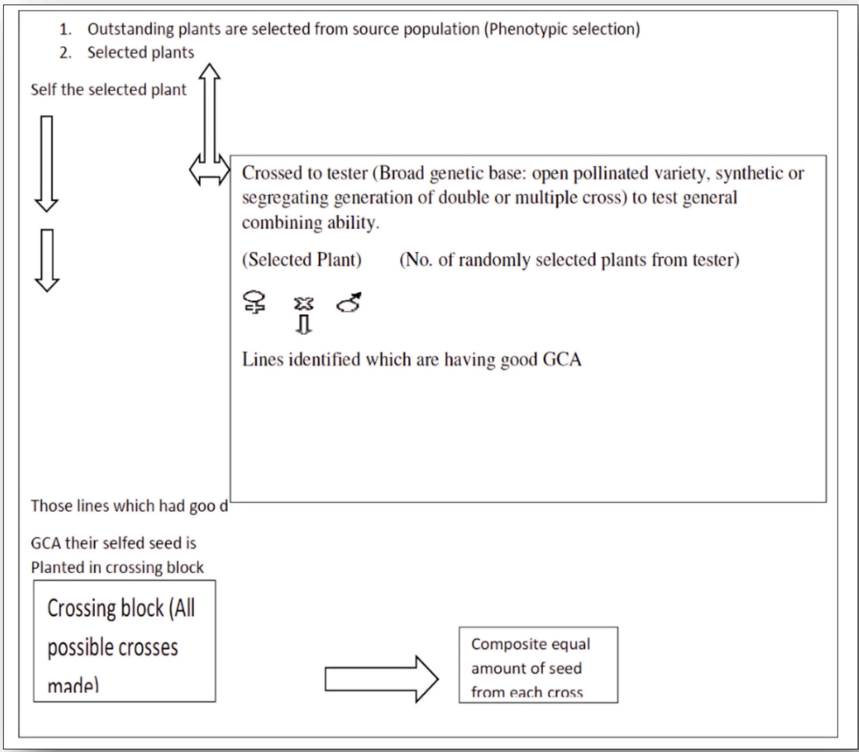

Figure 8.4: Procedure for recurrent selection for GCA, it remains same for RSSCA except tester. In RSSCA narrow genetic base[12]

Plants are chosen in the RS SCA method based on the performance of their progeny resulting from test crossings with a specified inbred tester. The selection is aimed at identifying plants that combine well with the specified inbred tester. These selected plants are expected to possess genes or gene combinations that interact efficiently with the genes present in the tester inbred. The RSSCA process is similar to that of General Combining Ability (GCA), with the exception that an inbred variety is used as a tester rather than an open-pollinated variety. The selected tester must be an extraordinary inbred because it will be one of the parents in the generation of hybrids employing the separated inbred lines from the enhanced population[5].

Reciprocal Recurrent Selection (RRS):

Comstock, Robinson and Harvey in 1949 proposed reciprocal recurrent selection. The primary goal of reciprocal recurrent selection is to strengthen two populations ability combine well with each other, improve the SCA and GCA in a population, may be used to developed synthetic variety and isolation of inbreed with superior GCS and SCA. Both population act as tester for the plant that selected from other population.

Procedure:

First year: phenotypically superior plant selected from population A and population B, selected plant is selfed, in population A each selected plants is crossed with random selected plants from population Similarly done with population B. Selfed seeds are harvested separately and saved for third year, Test crossed seeds are harvested separately and used to conduct replicated yield trail.

Second year: Replicated yield trail is conducted for both the population separately; superior progenies is identified on the bases of yield trail.

Third year: selfed seed from plants that produced superior progeny in replicated yield trail planted in Intercrosses block. All possible Intercrosses in made in each crossing block separately, equal number of seed from each intercross, composited for both populations separately, this complete original selection cycle[5].Same process is repeated for first recurrent selection.

8.3 Hybrid Varieties:

A hybrid is the outcome of crossing two genetically distinct plants. Alternatively, a hybrid is the F1 generation of a mating between two genetically distinct plant populations (a crossing among two pure lines, inbred, open-pollinated varieties, clones, or other genetically diverse populations). Hybrid variants are F populations that are cultivated for commercial purposes. The best way to take advantage of heterosis or hybrid vigor is using hybrid varieties. (Simmonds, 1979)[13] . The following are the primary characteristics of hybrids:

- The adoption of hybrid vigor or hybrid vigor across the variety makes the hybrid variety potent and advantageous.
- A hybrid plant has genetic similarities among all of its members. Hybrid populations are homogenous yet heterozygous. Because of their uniformity, they are more attractive.
- Because they can hybridize and withstand genetic information from two distinct parents, hybrids are better able to adjust to environmental changes than inbred and purebred kinds. (Dirks, 2009)[14]
- Hybrids can be formed in both cross-pollinated and self-pollinated species, depending on the hybrid vigor level. However, hybrids are more cross-pollinated than self-pollinated crops.
- In general, hybrids are more resilient to biotic and abiotic challenges than inbred and purebred types.

8.3.1 History:

Maize was the first crop to be commercially produced hybridally when it was determined that group and progeny selection could not significantly increase open pollination capabilities. In 1878, Beal observed that a small percentage of hybrids exhibited substantial (up to 52%) hybrid vigor and suggested raising the hybrids as commercial types.Shull suggested in 1909 that open-pollinated cultivars should continuously self-pollinate in order to produce inbred lines. Competitive hybrids are created by crossing inbred lines that perform well together to create superior hybrids. Jones published two hybrid investigates in 1918 and began distributing a hybrid variety (Burr Leaming Dent) commercially in 1922.

Hybrids entirely replace open-pollinated types in the late 1950s and early 1960s. In comparison to open-pollinated varieties, hybrid cultivars are estimated to yield an average of about 20% less in the United States. It is expected that the growth in India will be between 30 and 50 per cent. Davis (1927) introduced the idea of topcross hybrids for the initial evaluation of inbred lines. Jenkins introduced a reliable approach for double cross-performance prediction in 1934.One key element in the formation of hybrids is the application of cytoplasmic genetic male sterility. Taxas Cytoplasmic male sterility was identified in 1938 and brought to market for the production of hybrid seeds in the late 1960s.The potential of the inbred lines was further developed by the increase in population and the inbred lines' development. When the Maize Development Corporation was founded in 1952 in collaboration with the Rockefeller Foundation, extensive research into hybrid maize production in India got initiated. Four hybrids of maize were introduced in 1961: Deccan, Ranjit, Ganga 1, and Ganga 101.

The same year witnessed the onset of the development of hybrid cultivars of pear millet and sorghum based on the cytoplasmic genetic male sterility of Tift23A and Combine Kafir 60, respectively.1964, marked the production of the first jowar (sorghum) hybrid, CSHI, and the bajra (pearl millet) hybrid, HB1 (HB hybrid bajra), during the same year.

8.3.2 Types of Hybrids:

The commercially cultivated hybrids are of two types, viz (1) intraspecific hybrids, and (2) Interspecific hybrids.

A. Intraspecific Hybrid:

Intraspecific hybrids are crosses between individuals from the same species whose genotypes differ genetically. Another name for this is intervarietal hybridization. A lot of cross-pollinating crops as well as certain self-pollinating crops are commercially cultivated using this hybrid type. Hybrids within a species are consistently fertile. Based on type of cross, intraspecific hybrids are of three types:

a. Single cross hybrid: A single cross hybrid is the offspring of a cross between two inbreds or variations. These hybrids arise from a cross between two inbreds (A × B) in cross-pollinated species, whereas in self-pollinated species, they come from a cross between two homozygous variants.

- They develop in self-pollinated crops where heterosis can be exploited as well as in cross-pollinated crops.
- There are certain self-pollinating species where crossing is more common than cross-pollinated species.
- The total number of crossed lines is n(n-1)/2, where n is the inbred line.
- For instance, a hybrid in maize produces little, stunted grains, which makes it undesirable.
- Two- and three-way crosses can both be made better with a single cross.
- Single Cross is another tool for estimating double cross performance.
- A hybrid generates uniform plants and the highest possible hybrid.

b. Three-way cross hybrid: A three-way cross is the union of an inbred line and a single cross line. On maize, this hybrid is often applied. As an instance, a single cross denotes a female, while an inbred denotes a male. (A x B) x C.

- When there are merely three superior inbred genetic lines, this hybrid is produced. Male and female rows of maize are planted in a 2:1 ratio. incredibly outstanding and fantastic.
- Regular seeds are produced by this hybrid.
- The primary drawback of our hybrid is the pollen produced by the inbred male parent's low quality. (Allard, 1999)[15]

c. Double cross hybrid: The hybrid progeny from a cross between two single crosses is known as double cross hybrid. Such hybrids are commonly used in maize and sugar beet.

- Double cross hybrid involves four different inbred lines, viz (A×B) × (C×D).
- The shape and size of the double cross seed are constant because of the high pollen performance of F1 as the male parent and the high performance of F1 as the female parent.
- The rows of female and male parents are planted in 4:1 ratio in maize. Thus 80% of the area is covered by the female parent, whereas this ratio is 2: 1 in case of single cross and three-way cross hybrids.
- An inbred line has n (n - 1) (n-2) (n-3) / 8 potential double crosses, where n is the total number of relevant inbred lines.

Some other types of crosses are:

i. **Double Top Cross**: Double top cross hybrids have been also produced in maize. The hybrid progeny of a single cross and an open pollinated variety, or (A x B) x open pollinated variety, is known as a double-top cross hybrid. Top cross, also called inbred variety cross, is a cross between an open pollinated variety and an inbred line. Top crosses are usually not performed to produce commercial hybrid seeds, but rather to determine an inbred's ability to breed together. (Gama, 1977)[16]

ii. **Multiple Cross:** Multiple crossings are those that involve more than four inbred lines. In general, these crossings yield less than the optimal double cross combination. Known by another name, composite cross, multiple cross is a method of combining monogenic characteristics into a single genotype from various sources. More than one cross typically exhibits more adaptability.

iii. **Polycross**: Polycross is the process of openly pollinating a set of chosen genotypes apart from other compatible genotypes in order to encourage random mating between chosen genotypes.

B. Interspecific Hybrid:

Interspecific hybrids are F1 offspring of two distinct species within the same genus. Another name for this is an intraspecific hybrid. Due to their unusual fertility, interspecific hybrids are not frequently used in commercial breeding. Interspecific hybridization of *G. hirsutum*, a diploid variation, and *G. barbadense*, a tetraploid variety, occurs in cotton yields maximum yields. This place has produced a wide variety of tetraploid hybrids (such as Varalaxmi, DCH 32, DHB 105, Sruthi, HB 224, NHB12, and TCHB 213) as well as some diploid hybrids (DH7, DH9, Pha 46, and DDH2 cultivated in India). countless inbreeding as well.

8.3.3 Development of Hybrid Varieties:

The process by which hybrid variants are developed varies by species. There are three primary processes in the development of hybrid cultivars of maize:

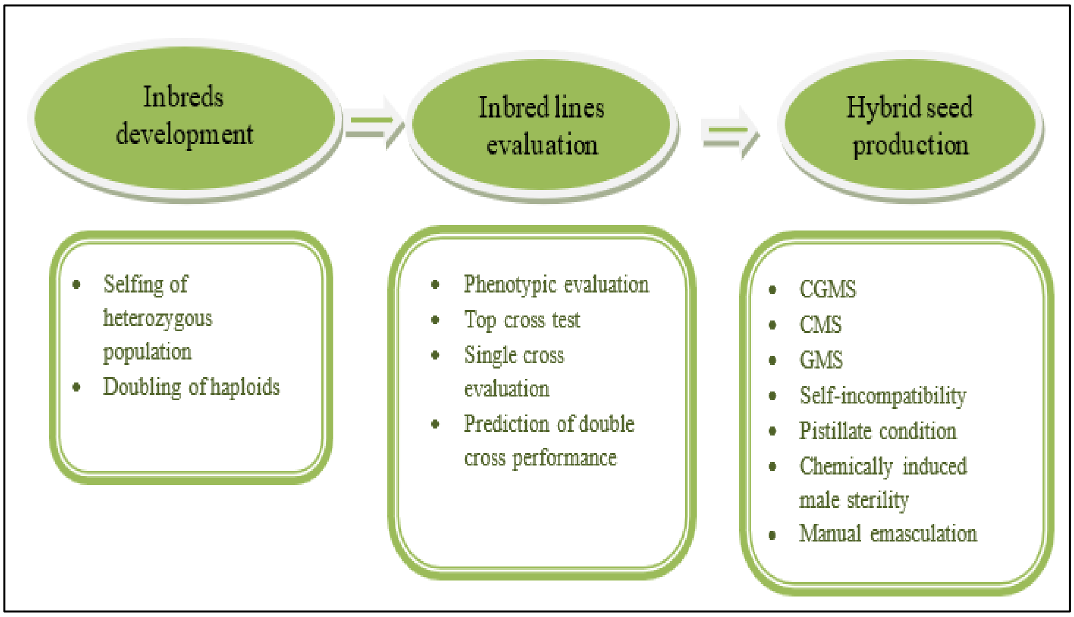

Figure 8.5: Process of development of hybrid

A. Inbreds Development:

For selfing, a number of populations can be used, including synthetic varieties, open pollinated types, and any other heterozygous population. Superior plants are selected and selfed based on their vigor, resistance to disease, and yield. The following season, the offspring of chosen plants are cultivated separately from the selfed seed. Again, the superior plants are self-pollinated and selected in each generation. Selfing is thus carried out for six to seven generations in order to produce excellent homozygous inbreds. Fixing desired genes in homozygous form and removing genotypes with unwanted harmful genes are the major goals of selfing. Colchicine therapy can also be used to double the number of chromosomes in haploids, resulting in inbreds. This is the quickest process for producing inbreds. When two independent or different inbred lines combine to produce a F hybrid, the vigor lost during inbreeding is regained. (Hayes, 1963)[17]

B. Inbred Lines Evaluation:

An inbred's potential is determined by its ability to perform it develops in a hybrid combination with other inbreds. The general combining ability (gca) and specific combining ability (sca) of the inbred lines are employed to evaluate them.

a. Phenotypic evaluation:
b. Top Cross Method: To create 100 single crosses, a number of inbred lines suggest that 100 are crossed to a common tester (an open pollinated variety). These crosses' yield performance is determined in replicated trials across multiple locations. Lines that provide a high yielding single cross when tested are chosen. Davis proposed this approach in 1927. This approach allows for the evaluation of many lines at once. The yield is evaluated against the average yield of each cross. High-yielding single crossings are typically produced by inbred lines which result in high yields in top crosses. This is the way general combining ability (gca) is measured. In this context, yield performance—rather than gca variations and effects—is referred to as combining ability. Planting alternating rows of inbred and open pollinated varieties and eliminating the tassel (male inflorescence) of the inbred line generates top cross seed.
c. Single Cross Method: The specific combining ability (sca) of the inbreds determined according to the best cross performance is determined using this procedure. The chosen lines are crossed in every possible way, or n(n-1)/2, where n is the total number of inbred lines (reciprocals excluded). The yield performance of these single crossings is determined in replicated trials conducted at multiple locations. The best-performing single crossings are selected to be utilized in double cross hybridization or released as a variety. Only a certain number of inbreds can be evaluated at once using this procedure, as handling more inbreds in a crossing lead to in a large number of single crosses.

Time of Testing: Starting with the third, fourth, and fifth generations of inbred lines, one should determine the overall connection of these lines. According to some study, visual selection helps early learners coordinate better.

C. Hybrid Seed Production: After identification of superior inbred lines, the hybrid seed is produced. Three types of interparietal hybrids, viz. (1) single cross hybrid, (2) three-way cross hybrid, and (3) double cross hybrid is produced. In case of single- and three-way cross hybrids, the rows of female and male parents are planted in 2: 1 ratio. The tassels of female parents are removed and natural cross pollination is allowed. In case of three-way cross hybrid, the single cross hybrid is used as female parent and inbred lines as male parent. In case of double cross hybrid, the rows of female and male parents are planted in 3: 1 or 4: 1 ratio.

The tassels of female single cross are removed so that it is pollinated by the pollen of single cross used as male parent. The seed production is carried out in isolation to prevent crossing with other compatible genotypes and maintain the high genetic purity. (Saxena, 2010)[18]

8.3.4 Merits:

- Hybrid varieties are more productive than synthetic, mixed and open pollinated varieties.
- Hybrid varieties are more consistent and attractive than synthetic, mixed and open-pollinated varieties.
- Hybrid varieties can be produced as self-pollinated varieties and cross-pollinated species, while synthetic and composite materials are associated with cross-pollinated crops.
- Hybrids can reproduce with the same genotype, which is not possible in mixed and open-pollinated species.
- Hybrid varieties take advantage of heterosis's GCA and SCA components. For this reason, they make the most of heterosis.
- Parental inbreds are raised in isolation and undergo selfing or sibmating in order to maintain hybrid variations. This ensures that a hybrid variety's genetic makeup won't alter over time, with the exception of rare spontaneous mutations. Conversely, due to accidental and deliberate artificial selections, the genetic makeup of open-pollinated, synthetic, and composite types is likely to alter over time.
- Hybrid variants yield 25–30% more than pureline lines in many self-pollinated crops. Because of this, even though hybrid seed is expensive, farmers are starting to favor them.

8.3.5 Demerits:

- Because segregation and recombination result in the hybrid in F1 to create numerous varieties, fresh seed needs to be produced year.
- Hybrid seed is more expensive than synthetic, composite, and open-pollinated kinds; farmers must buy new seed each year.
- To reach their full potential, hybrid plants need extra input (fertilizer, water, plant protection, etc.) throughout cultivation.
- In comparison to synthetics, composites, and open pollinated types, the production of hybrids demands a higher level of technological expertise and specific regions.
- Easy emasculation of the female parent and sufficient pollen dissemination from the male parent are prerequisites for the large-scale production of hybrid seed. Pollen dispersal and emasculation are either difficult or unsatisfactory in many species.
- In certain species, such as the majority of self-pollinated crops, hybrid varieties cannot be commercially produced unless breeding or genetic modifications sufficiently modify their floral biology.

- The strict standards of isolation are typically difficult to meet, except in big farms, in the majority of cross-pollinated species. This makes producing hybrid seeds challenging in a nation like India where most farms have minor land holdings.
- The produce (grain F generation) of a hybrid variety (F_1 generation) will not be of uniform quality if there are noticeable differences in grain quality between the parents of the variety. One of the drawbacks of the first rice hybrids introduced in India was this, although it has been fixed in the more recent models.

8.4 Synthetic Varieties:

In 1919, Hayes and Garber developed synthetic types of maize for commercial production. All the connections among distinct insect species that mix well and are maintained by independent open pollination are crossed to create synthetic variants. As is evident, these diverse synthetics are basically a synthesis of several cross-hybrids. In breeding cross-pollinated crops in situations where pollination is challenging to regulate, synthetic varieties can be helpful. (Sharma, J. R. (1994)[19]

8.4.1 Features of Synthetic Varieties:

- Cross-pollinated crops are relevant to synthetic variations. These cultivars include alfalfa, pearl millet, maize, and several other cross-pollinated plants.
- Clones, open pollinated varieties, and inbreds may all be utilized to create synthetic varieties. Synthetic variety is typically made up of recurrent selection end products that have already undergone GCA testing. Generally, a synthetic variety is made up of five to eight good generals combining inbreds.
- The utilization of heterosis, or hybrid vigor, is the fundamental idea behind the production of synthetic varieties. These kinds of lines are made up of complete inbred combinations. Whereas hybrids focus more on non-additive (over-dominance and epistatic) gene action, synthetics are more interested in additive gene action.
- A few heterozygotes are the basis of synthetic variations. Open pollination maintains varieties vital and promotes some degree of self-propagation, which results in some seed fixation. Offspring therefore contain a number of heterozygotes and homozygotes of the synthetic variety. This explains the several breeds of many synthetics.
- Stable and polymorphic are synthetic variants. As a result, a lot of synthetics can adjust well to changes in their surroundings. To put it another way, synthetic materials can yield consistent outcomes in a changing environment.
- Because of their heterogeneity and wide genetic diversity, synthetic varieties exhibit good resistance to plant diseases.
- Without using any more resources, synthetic crops can grow successfully for four to five years (Lonnquist and McGillus 1956)[20]. Reproductive ability can be sustained over many generations by mass selection. Farmers can thus use their seeds for a period of five years. After five years, it's preferable to build a large number of synthetics.
- New structures and new rules must be the foundation of any redevelopment. When compared to open-pollinated fruits, synthetic crops always yield more; yet, their yield is less than that of single- and double-crossed hybrids.
- The primary benefit of synthetic cultivars over hybrid ones is the lower cost of their seeds.

8.4.2 Development of Synthetic Variety:

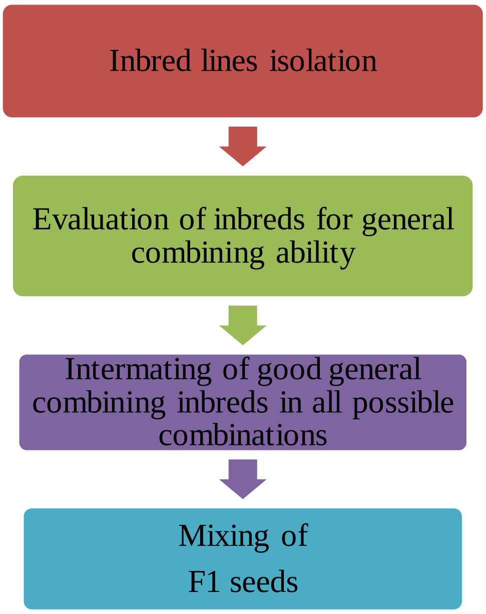

Figure 8.6: Process of Development of Synthetic Varieties

A. Isolation of Inbreds: Synthetic materials are generated using a variety of materials, including clones, open pollinated varieties, inbred lines, and material developed through recurrent selection. Jenkins (1940) proposed that the creation of a synthetic variety may be accomplished through the use of inbred lines that self after one generation.

When the parental material is made up primarily of clones or inbreds, the synthetic variety created from inbred lines can be precisely reproduced. Since short term inbreds are also heterozygous for numerous gene loci, exact reconstitution is not possible when the parental lines are either short term inbreds or open pollinated populations. (Kaul, 2009)[21]

B. Evaluation of Inbreds for GCA: It evaluates the general combining ability of inbred lines. The polycross method, single crosses, and top cross method are the three ways to assess inbred lines for general combining ability (GCA). In a top cross, an inbred is crossed with a common tester, and the resulting progeny are assessed in multiple trials for yield contributing characteristics and general yield combining capacity.

Selected inbreds are permitted to mate in isolation by open pollination in polycross. In a replicated study, the top cross progeny is assessed for gca of yield using a local check. The third approach involves making every single cross possible between pre-selected inbreds.

Using local variety as a check, these crosses are assessed for gca of yield in a replicated study. As a result, inbred lines with strong general combining capacity are found and ultimately chosen for the creation of synthetic varieties. (Albrecht, 2011)[22]

C. Intermating of Good General Combining Inbreds: Inbred lines selected for superior gca are crossed in all possible combinations. The all-possible single crosses would be n(n-1)/2, where n is the number of inbred lines. The seed of each cross is obtained in adequate quantity to produce a synthetic variety.

D. Mixing of F1 Seeds: In order to produce a synthetic variety, the seeds of all potential F1 crossings between the chosen inbred lines are combined in an equal amount or number. The variety that was thus created is known as Syn. Typically, this type of variety's seed is provided to farmers for commercial production after undergoing one or two generations of open pollination in isolation (Syn1, Syn2).

Table 8.1: Development of synthetic variety from already available inbred lines

First year	-	• selection of inbred lines • crossing with common tester • harvesting top crossed seed separately
Second year	-	• evaluation of top crosses using check • identification and selection of good general combining inbreds
Third year	-	• making all possible single crosses among inbred lines selected fot good GCA • harvesting crossed seed of single crosses separately
Fourth and fifth year	-	• mixing seed of single crosses in equal quantity • seed multiplication by open pollination in isolation for 1 or 2 generations
Sixth year	-	• release as a new synthetic variety • distribution of seed to the farmers for commercial cultivation

8.4.3 Factors Affecting Performance of Synthetic Varieties:

A. Number of Inbred Lines: The quantity of inbred lines that make up a synthetic variety determines its performance. It was found that in maize, the yield of synthetics improved with the number of inbred lines up to five years, after which the yield decreased (Kinman and Spague, 1945)[23].

Prepotency decreased as a result of including more inbreds than five, which decreased yield. Heterozygosity increases due to an increase in diversity, which compensates for prepotency as many as five inbred lines. When only five or six of the best combining inbreds were included, the highest yielding synthetic variety was produced.

B. Mean Performance of Inbreds: Additionally influencing the yield potential of synthetic varieties is the mean performance of parental inbreds. The yields of a synthetic variety's component lines are found to positively correlate with each other.

High-yielding synthetics are produced by strong inbreds with high yields. (Chase,1969)[24] Conversely, when less robust and low yielding lines are employed as constituent lines, low yielding synthetic types result. While testing for combining ability, the performance of inbred lines can be assessed. Top cross performance can be used to identify high combining inbreds. When the yields of parental lines are large, the yields of synthetic variety reach their maximum. Furthermore, when the yields of parental lines are high, fewer parental lines are needed to generate high yielding synthetics.

C. Mean Performance of F1 Crosses: High yielding synthetic cultivars should result from high performance F1 crosses. Therefore, an increase in the F1 mean yield will raise the synthetic variety's yield level.

8.4.5 Merits:

- In crop species where pollination control is difficult or impossible, synthetic varieties provide a practical way to use heterosis where commercial hybrid variety manufacturing would not be feasible.
- Grain developed from a synthetic variety can be used as seed by farmers to grow their next crop. The synthetics can be maintained from open-pollinated seed for several years if precautions are made to prevent contamination by foreign pollen and to choose a suitably large number of plants to prevent inbreeding. Farmers are spared the annual expense of buying new seed as a result. (Collard, 2008)[25]
- Because their genetic base is greater than that of hybrid types, synthetics are expected to perform better in adaptable conditions.
- Compared to hybrid varieties, the cost of seed for synthetic types is comparatively lower.
- Synthetic varieties are good stores of genetic variety; hybrid variants require more skill in seed production than do synthetic types.
- There is strong evidence that population improvement can significantly enhance synthetic variety performance without significantly lowering variability. This is an opportunity for ongoing advancement in synthetic variants.
- Due to their high genetic heterogeneity, synthetic varieties offer superior defense against the introduction of novel disease races.

8.4.6 Demerits:

- In general, synthetic types perform worse than single- or double-cross hybrids. This is due to the fact that hybrid types utilize both GCA and SCA, whereas synthetics (and composites) exclusively utilize GCA. (Kalloo, 2006)[26]
- Lines with relatively lower GCA have a negative effect on synthetic performance. Because lines with exceptional GCA are few, it is frequently necessary to add such lines in order to enhance the number of parental lines that make up the synthetics.
- While hybrid variants can be developed in both self- and cross-pollinated crop species, synthetics can only be produced and maintained in cross-pollinated crop species.
- Because of their higher variability and heterogeneity, the product of synthetic kinds is typically less uniform and less aesthetically pleasing than that of hybrids.

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