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Breeding Methods



By Asheesh Singh, Arti Singh (ISU)



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Introduction

The results of breeding and selection may be new varieties or clones that are superior to currently used standard commercially grown genotypes (checks) according to some criterion or criteria, or populations that are superior to previous ones. Several breeding strategies exist and though some methods are generally commonly accepted, different methods are applied in different crops as they are more efficient and effective based on the type of mating of different crops, resources and objectives. In other words different breeding strategies are deployed and used to maximize superiority per unit cost and time. Also depending upon the goals of the breeding program, different strategies may be used simultaneously or at different stages of the program.

Objectives

Learn different plant breeding methods relevant to crops grown in Africa.

Methods Used in Self-Pollinated Crops

In self-pollinated crops, the following breeding methods are commonly used to develop pure-line cultivars:

- Bulk method
- Pedigree methods
- Single Seed Descent
- Doubled Haploid

Example of self-pollinated crops in which these methods are used include: common bean, soybean, cowpea, groundnut, rice, wheat, barley, millet, sorghum.

In specific situations, for example, when a breeding program is converting pure-lines to contain a specific gene or 2-3 genes (of qualitative inheritance), backcross breeding method is used.

The doubled haploid method is not used in legume crops as these species have so far been recalcitrant to tissue culture and haploid induction and rescue.

Methods Used in Cross-Pollinated Crops

In cross-pollinated crops, the following breeding methods are used to develop cultivars:

- Recurrent selection (for example, maize)
- Development of hybrids: a 2-step process where first inbred lines are developed and assessed for their specific combining ability, followed by crossing of the inbred lines (generally, 2 inbred lines, but can be 3 or 4) to produce hybrid, as for example, maize, rice, sorghum, cotton.

Few self-pollinated species (such as rice, sorghum, cotton) have some level of outcrossing and expression of heterosis, which is exploited to develop hybrid cultivars.

Recurrent selection methods are used to develop open-pollinated varieties or synthetics.

Methods Used in Clonal Crops

The crop species that can be clonally propagated present unique advantages:

1. Heterosis can be fixed in F_1 and in subsequent crop production cycles, and its clones can be propagated to preserve the high yield advantage.
2. Farmers can harvest the crop and use the vegetative plant part to grow the next crop. For example, potatoes, sugarcane, cassava.

In breeding clonal cultivars, hybridization is made between two clones and a large F_1 population (remember that parental clones are heterogeneous and heterozygous) is screened as each F_1 is unique and different from other F_1 s. This process is repeated over different crop cycles to identify the superior clone for release as a new cultivar.

Breeding Methods Used in Major Crops

Pedigree Method

Pedigree Method: Introduction

The pedigree method of breeding is used in development of both self-pollinated (to develop pure-lines) and cross pollinated crops (to develop inbreds). It is one of the most commonly used breeding methods. Selection of highly heritable traits is practiced in early generations on individual plants. Yield testing is generally done once homozygous lines are developed. However, in an early generation testing procedure or a modified pedigree method, yield testing is done in early generations while within-family selection is still ongoing.

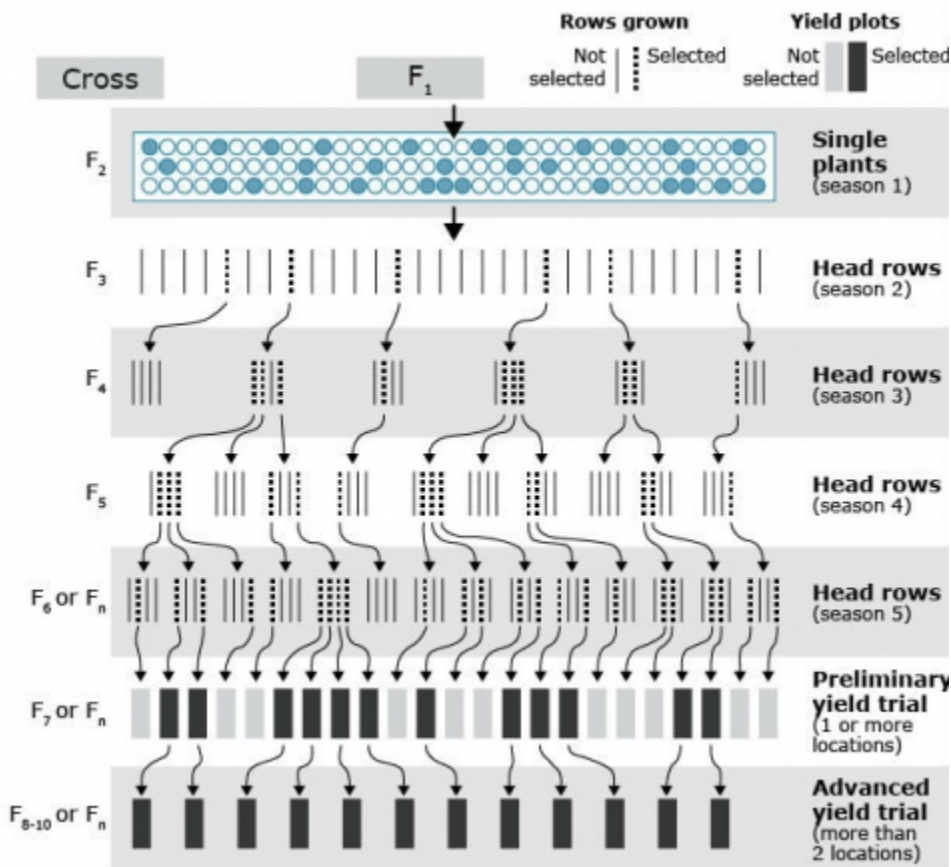


Fig. 1 Flow chart of pedigree method of breeding.

Pedigree Method

- Select in F_2 and later generations.
- Selected F_3 plants (or seed from inflorescence of selected plants) grown in next season (in winter nursery if available).
- Selected F_3 rows (or selected plants within rows) grown as F_4 in rows (or yield plot).
- Selected F_4 plants (or seed from inflorescence of selected plants) grown in next season (in winter nursery if available) as F_5 .
- Repeat this process until selection is effective (remember, additive genetic variance among lines increases but decreases within lines as selfing is used).

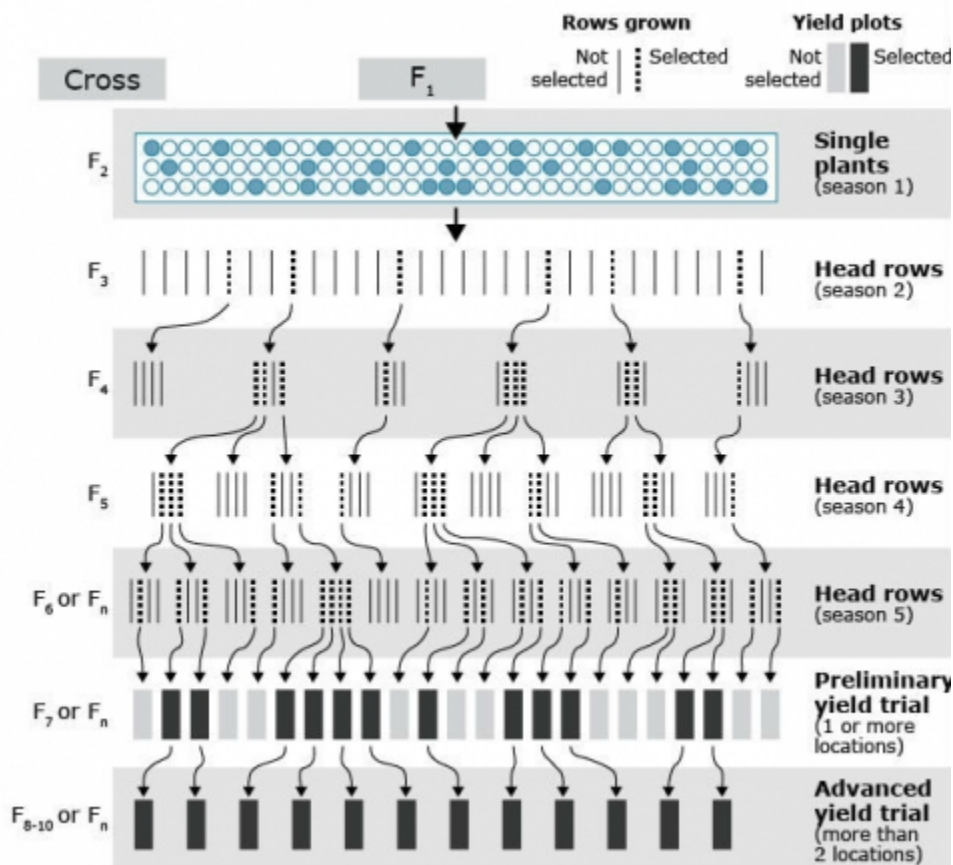


Fig. 1 Flow chart of pedigree method of breeding.

Pedigree Method

- Bulk harvest the last generation when a row is grown (and appears homogenous), and plant in next season as a yield plot.
- Grow through successive seasons of yield testing to select the genotypes that are superior to checks.
- Pedigree information is kept to maintain family information, which allows to select more plants from families that are superior performing or to advance families for yield testing if those families are superior.

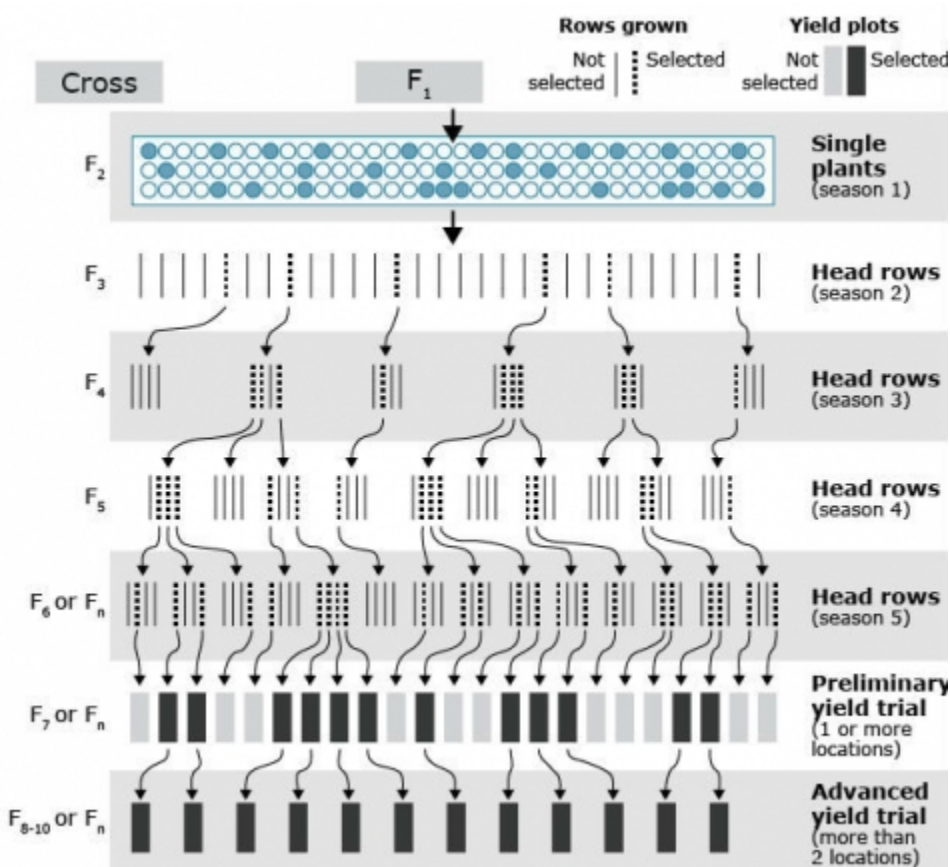


Fig. 1 Flow chart of pedigree method of breeding.

Pedigree Method

- Number of plants/row and population sizes vary between programs and some estimates can be obtained from text books or plant registration documents. These numbers will depend on the objective of the cross, number of crosses made per year, available resources (technical, infrastructure).
- Selection for other specific traits is simultaneously happening (on harvested seed, or specific nurseries).
- Single plants or inflorescence per plant are selected at each generation, but in some visibly inferior rows, breeder may not make any within rows selection (i.e., practice among row selection).
- Selection can be practiced in winter nursery if genetic correlation is high among home location and off-season location (i.e. winter/dry season nursery locations).
- Breeder may combine two or more methods of breeding and these methods will then be called modified pedigree (or modified bulk, or modified single seed descent etc.).

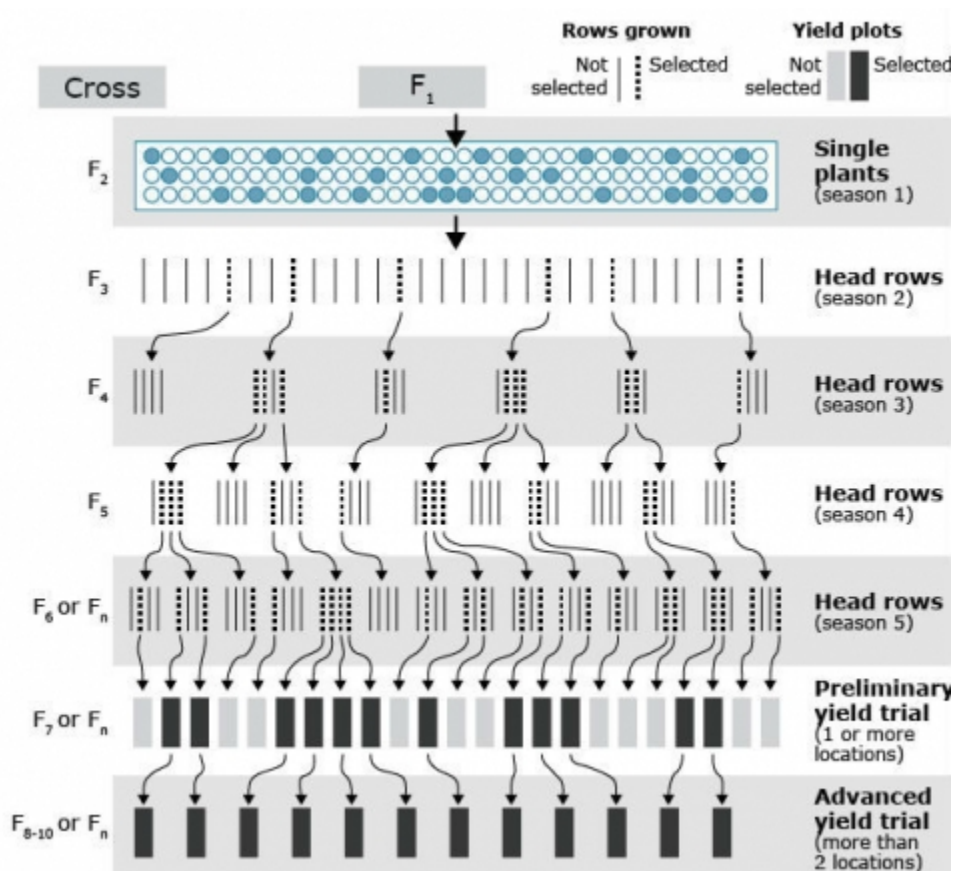


Fig. 1 Flow chart of pedigree method of breeding.

Bulk Method

Bulk method allows natural selection to act and remove undesirable genotypes from the population (i.e., per cross). The choice of growing environment will dictate what kinds of traits will be selected for or against, therefore care needs to be exercised to use environments that are suitable for realizing the objectives of the program.

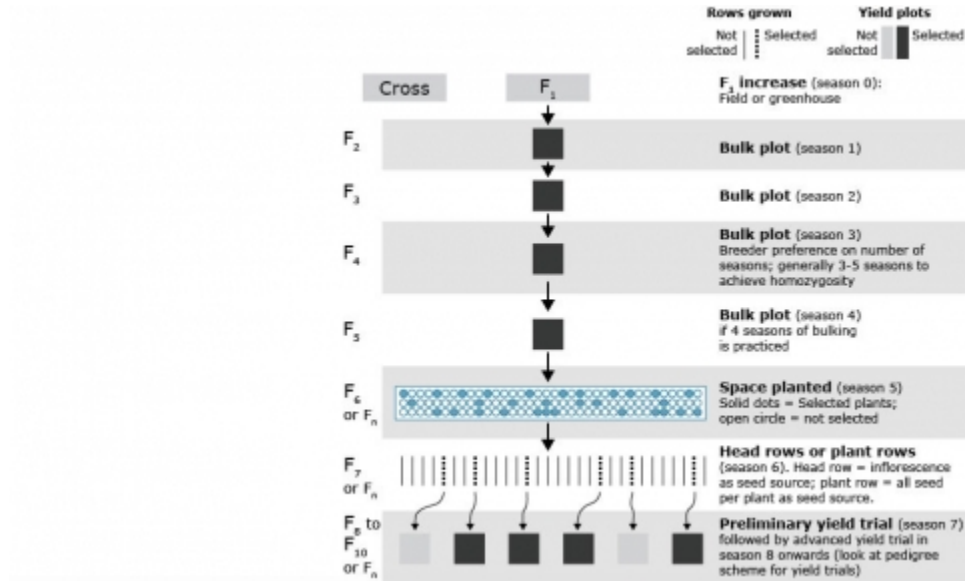


Fig. 2 Flow chart of bulk method of breeding.

Bulk Method

- Generations are advanced to homozygosity through bulks.
- Low cost, less technical method of breeding.
- Natural selection is used to remove undesirable plants.
- Artificial selection environment can be used to select for a trait of interest. Bulks can be grown in a disease or another stress nursery to select for that trait. Markers can also be utilized to select for desirable traits to constitute the bulks. These variations will make the scheme as a modified bulk method.

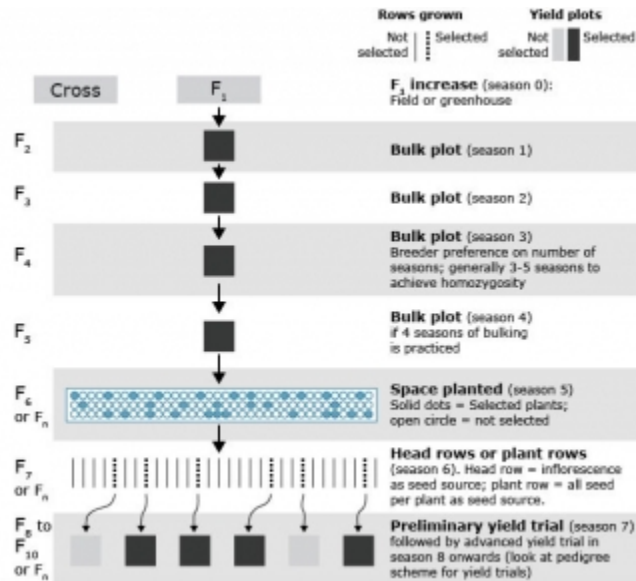


Fig. 2 Flow chart of bulk method of breeding.

Bulk Method

- Early generation testing of bulk may be done for yield testing and to make a decision on retention of populations based on ranking among populations.
- In modified bulk method, single plants or inflorescence per plant are selected at each generation; while in bulk method, plants from the entire population are harvested and seeded (all or sub-sample of seed) in next generation.
- Lighter shade yield plot = grown, tested, not selected; darker shade yield plot = grown, tested, selected and advanced to next generation testing.

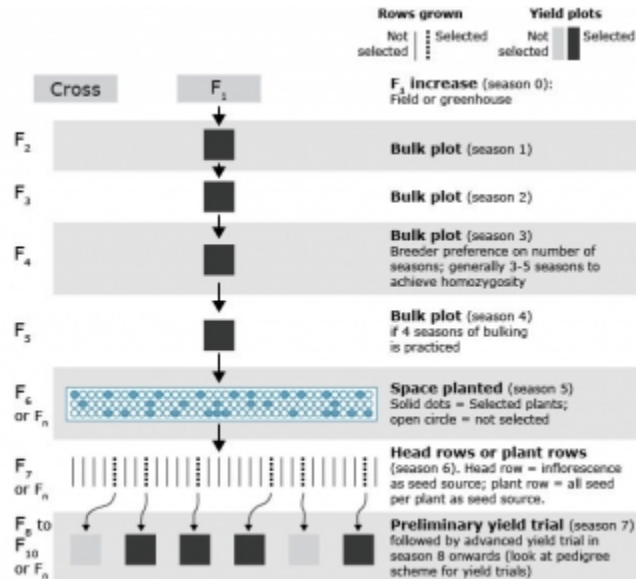


Fig. 2 Flow chart of bulk method of breeding.

Single-Seed Descent Method

Single Seed Descent (SSD) was developed as a breeding method to rapidly advance lines to homozygosity so that selection can be practiced on homozygous lines. The original intent of this method was to maintain a large population size to mimic the genetic variation in F_2 generation for effective selection. However, this method is now used to reduce the time to develop cultivars. (Sleper and Phaelman, 2006).

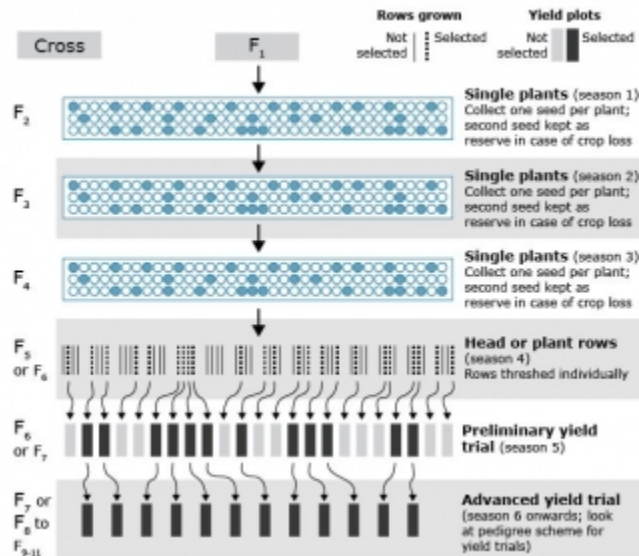


Fig. 3 Flow chart of single seed descent method of breeding.

Single-Seed Descent Method

Single-Seed Descent Method

- Generations are advanced to homozygosity rapidly. In case of small grain crops (such as wheat, barley, oats), three seasons can be completed in artificial growing conditions (greenhouse etc.), and limited space is needed to keep a population size of 250-300 seed per cross.

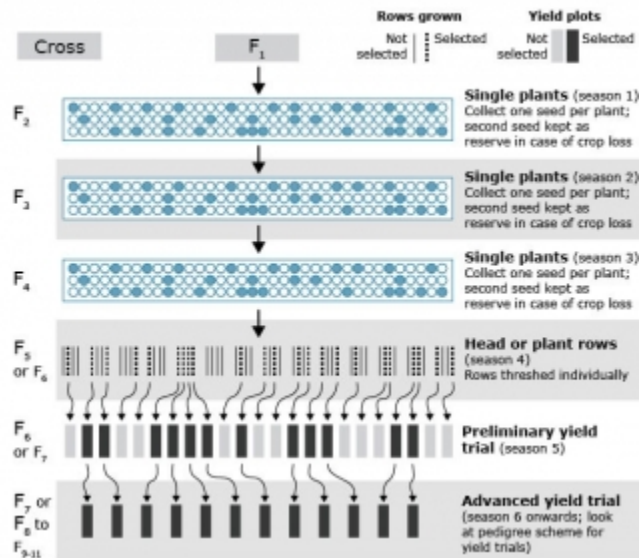


Fig. 3 Flow chart of single seed descent method of breeding.

Single-Seed Descent Method

- If true single seed descent is practiced (where one seed per plant is grown in successive generations, population is reduced in each cycle due to losses at germination and emergence. As an alternative modified single seed descent can be used where 2-3 seed per plant are planted in hill plots in each cycle, and 2-3 seed from each hill are collected from an inflorescence.
- SSD plots can be grown in a disease or another stress nursery to select for that trait.
- It is a cheaper, less technical method of breeding. Rapid inbreeding and homozygosity is achieved.
- No need for record keeping of individual plants while advancing through SSD.
- Open circle = single plants (or hills in modified SSD) per population.

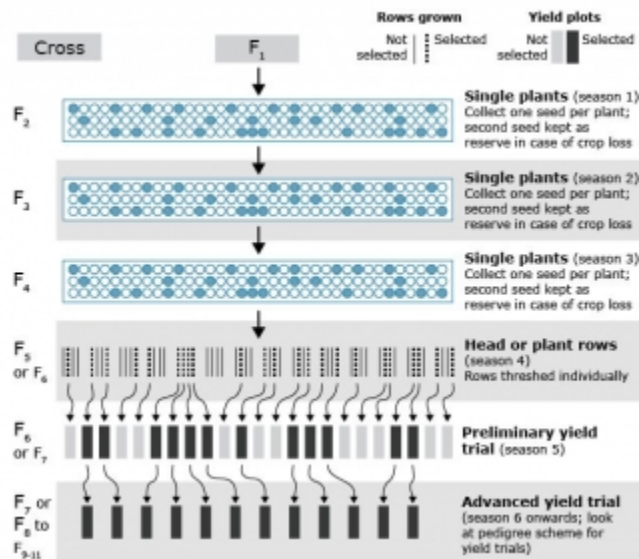


Fig. 3 Flow chart of single seed descent method of breeding.

Doubled Haploid Method

Doubled haploids (DH) are created by generating haploid plants from microspores (androgenesis) or unfertilized eggs or ovules (gynogenesis). Haploid plants are then subjected to a chemical treatment (with colchicine) to double their chromosome number to produce homozygous diploid plants.

Doubled haploids are generated from heterozygous plants, typically F_1 plants derived from crossing of two pure-lines or inbred lines. DH can also be developed from selected F_2 individuals from a cross. This method is used in development of both self-pollinated (to develop pure-lines) and cross pollinated crops (to develop inbreds).

- Generations are advanced to homozygosity in single generation. DH genotypes are true homozygous.
- Specialized lab is needed to create doubled haploids. Can be generated through a service provider.
- Population size is an important consideration because one only generation of meiosis occurs (at F_1).
- This method is suitable for marker assisted breeding to select for traits that are fixed.
- Can develop cultivars most quickly. If sufficient seed is available, can go to advanced yield trial in season 3.
- It is becoming a preferred method of inbred line development in maize.

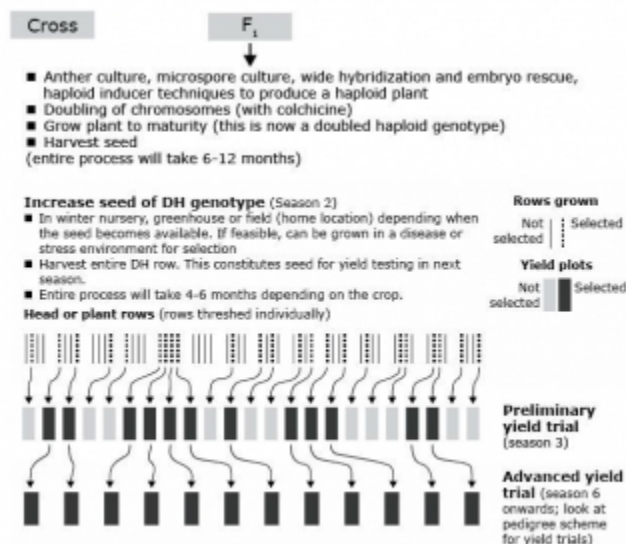


Fig. 4 Flow chart of doubled haploid method of breeding.

Backcross Breeding Method

Backcross breeding method is used if the objective is to introgress a gene into an elite cultivar or breeding line. Examples, are disease resistance gene(s) and herbicide tolerance gene(s). By crossing to the recurrent (adapted) parent, the newly developed cultivar will contain majority of the recurrent parent genome and only the gene of interest from the donor parent.

If the gene to transfer is recessive (*rr*), progeny of crossing with *RR* recurrent parent will segregate as *RR* and *Rr*, and therefore progenies are selfed for one generation to determine the *Rr* type versus *RR* types (*RR* are discarded) before making the next backcross. With the application of molecular markers, this extra step has become redundant and *F*₁ plants can be grown, DNA extracted from young plant tissue to determine *Rr* and *RR* types. *RR* types can be removed and crosses can be made with *Rr* types.

For backcross breeding program, if the gene to be moved comes from an unadapted or related species, the breeder has to be aware of inadvertently bringing in undesirable genes linked to the desirable target gene (termed linkage drag). Larger population sizes will need to be grown to identify recombinants. Innovations, e.g. marker assisted backcrossing, marker assisted recurrent selection, genomic selection, exist that reduce the need for large population sizes.

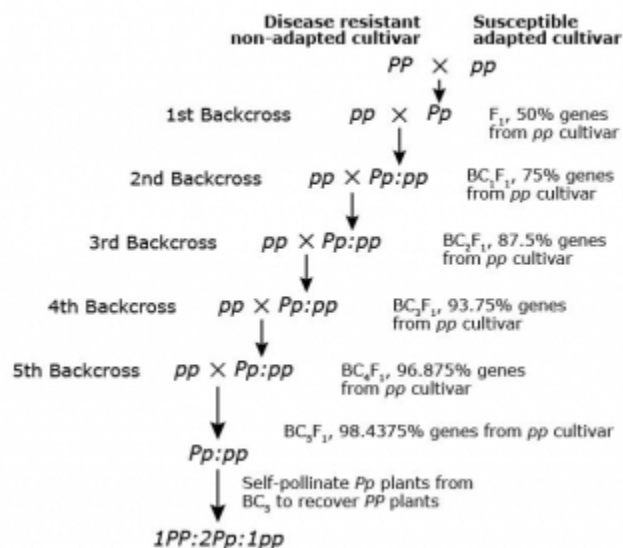


Fig. 5 Flow chart of backcross method of breeding.

Marker-Assisted Recurrent Selection

Reliability for Selection

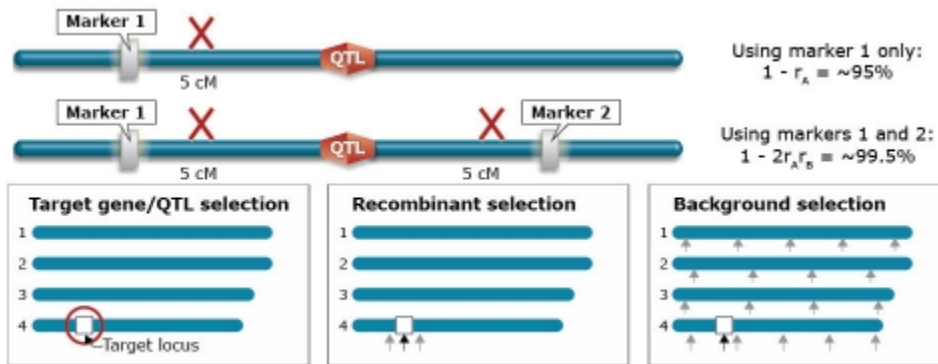


Fig. 6

Comparison of Target Gene/QTL, Recombinant and Background selection methods. Adapted from International Rice Research Institute, 2006.

In Target gene/QTL selection, Markers may be used to screen for the target trait, which may be useful for traits that have laborious phenotypic screening procedures or recessive alleles.

In Recombinant selection, Selecting backcross progeny with the target gene and tightly- linked flanking markers in order to minimize linkage drag.

In Background selection, Selecting backcross progeny (that have already been selected for the target trait) with background markers. In other words, markers can be used to select against the donor genome, and this will accelerate the recovery of the recurrent parent genome.

Steps

Marker-Assisted Recurrent Selection

- i. One generation of phenotypic selection in the target environment is conducted,
- ii. Markers with significant effects are used to predict the performance of individual plants, and
- iii. Several generations of marker-only selection are performed in a year-round nursery or greenhouse

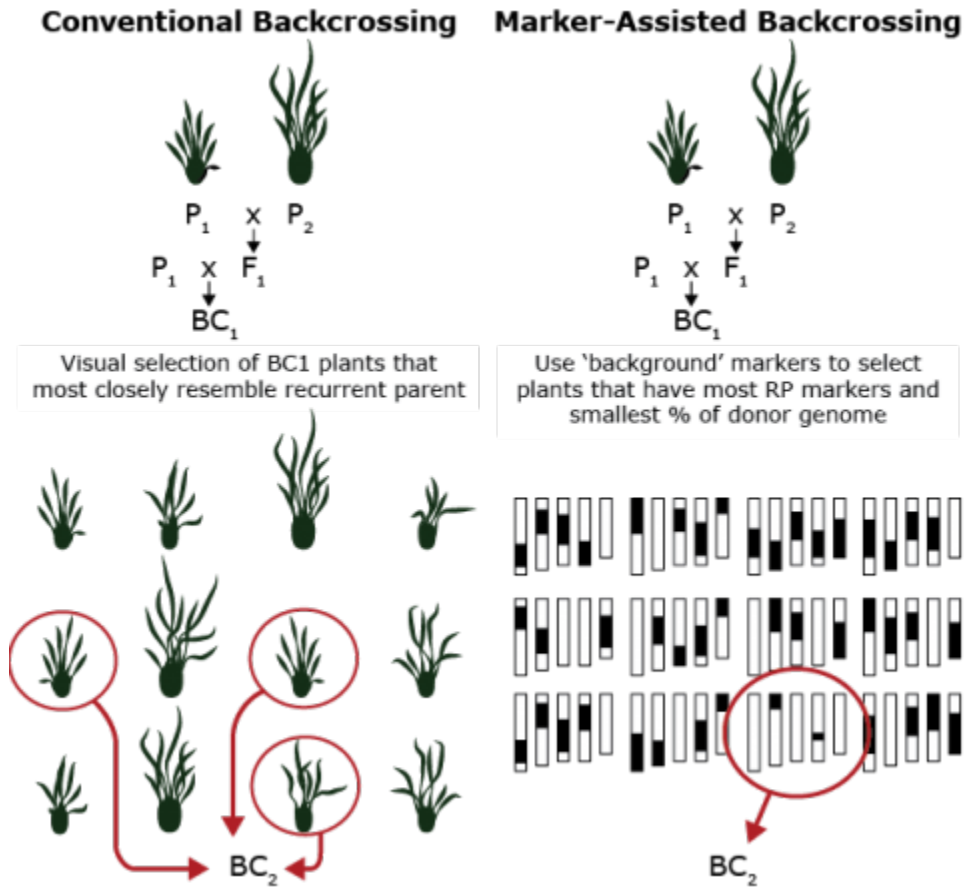


Fig. 7 Conventional versus marker-assisted backcrossing. Adapted from International Rice Research Institute, 2006.

Early Generation Testing

Early Generation Testing describes the procedure for selecting superior lines of families before they are homozygous. It also refers to a specific use where a genetic worth of a population is determined by analyzing yield data from a segregating (early generation) plot and removing entire populations.

In the pedigree breeding method we looked at individual plant selection for highly heritable traits in early generations. With high heritability, individual plant selection is still effective, for example traits such as plant height, disease resistance, and morphological traits. Several breeding programs, however, follow a modified method (such as modified pedigree method), in which yield testing is started in early generation (for example, F_3 or F_4) to make selections. The early generation lines are grown on yield plots (2 or 4 row plots), therefore, more resources are required to handle EGT. Nonetheless, EGT allows elimination of materials (lines) that are inferior due to use of replication and multi-environment testing. Also, selection for lower heritability can be practiced to discard inferior lines.

Other breeders may choose to perform a yield test on populations derived from early generation bulks to identify superior bulks (inferior bulk populations are removed completely from further generation advancement). Thus, EGT testing in this scenario can be done for one or 2 generations followed by selection of superior plants, and then starting yield testing of these lines.

CMS Systems

Plant breeders working with Cytoplasmic male sterility (CMS) systems will aim to develop new 'B-lines' and 'R-lines'. In crops where CMS system is used to produce hybrids, different 'R' restorer genes are identified and breeders will improve 'R-lines' that will be used as males in creation of hybrids. 'B-lines' and 'R-lines' are developed using the self-pollinated breeding methods we learned about earlier in this module (pedigree, bulk, SSD, DH etc, or a modified method = combines more than one method in the development of breeding line of cultivar).

Fig. 8 shows an outline of a CMS system. Look closely at the 'R' and 'r' genes in nucleus and 'S' and 'F' genes in cytoplasm.

A breeder who develops 'B-lines' will use backcross method to develop 'A-lines' using available CM sterility genes. Hybrid cultivar is produced by crossing of 'A-lines' with 'R-lines'. The A/B and R gene pools are considered separate gene pools (reproductive gene pools) similar to heterotic gene pools we learned about in maize systems.

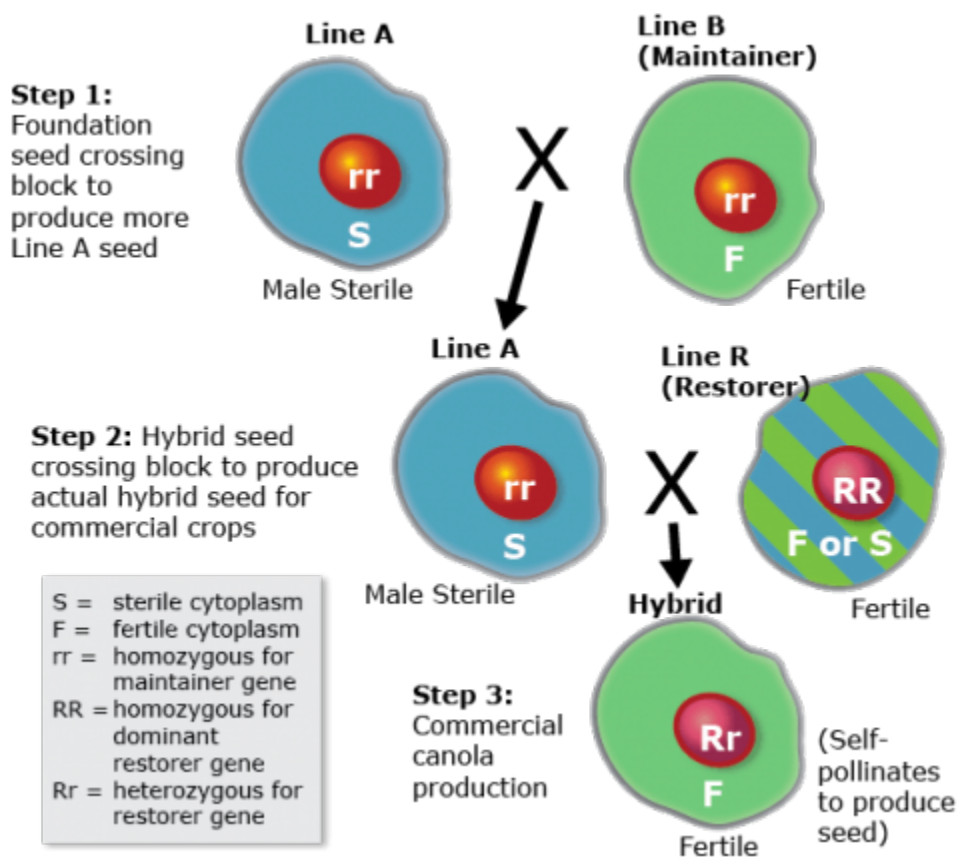


Fig. 8 Use of CMS system in hybrid seed production. Adapted from Canola Council of Canada.

Hybrid Cultivars

In the module on Steps in Cultivar Development, we looked at the development of maize hybrids using two-way crosses. Crosses are made within a heterotic group to develop superior inbred lines in the heterotic group. These inbred lines are crossed to testers from other heterotic groups to decide on the best specific combining ability. This process is repeated for all heterotic groups that the breeding institution or company works with internally.

For evaluation, superior inbred lines from dissimilar heterotic groups are crossed to produce hybrids. Several 100 or 1000's hybrids are evaluated each year to finally pick the most superior hybrid(s) for commercial release based on their performance and target area of adaptation (maturity, stress, environment etc.).

Hybrid seed is produced by growing inbred female rows (say 6 to 8) from one heterotic group and inbred male rows (1 or 2) from a dissimilar heterotic group interspersed among the sets of female rows) and de-tasseling the female rows (that is, removing male inflorescences from female plant rows) before pollen shed. Manual or mechanical tools are used to de-tassel (prior to pollen being ready or shed to avoid any selfing of plants of the inbred female line). Cobs from female rows are harvested and these constitute the hybrid seed. In some programs, but routinely done in private seed industries, the male rows are usually destroyed when pollination is completed to avoid contamination from cobs from inbred male plants if allowed to grow and produce cobs.

Purpose

In recurrent breeding and selection, parents of a crop species are crossed to develop populations using various mating designs described in the Crop Improvement module “Refresher on Population and Quantitative Genetics.” Based on one or more selection criteria, and using within family and among family selection strategies, individuals are selected and inter-mated to produce the next generation. This procedure of selection can continue for an indefinite amount of time, hence the term “recurrent”. Recurrent selection method is employed in order to achieve the following:

- The goal of recurrent selection is to improve the mean performance of a population of plants and to maintain the genetic variability present in the population.
- The underlying principle of recurrent selection is to increase the frequency of desirable genes that the breeder is attempting to improve.
- Recurrent selection is used to improve populations in cross pollinated species. Open pollinated varieties are one type of cultivar developed using recurrent selection.

Comparisons

Mass Selection Vs. Phenotypic Recurrent Selection

Mass selection: Female plants are selected after pollination with unselected and selected pollen source.

Phenotypic recurrent selection: Male and female are both controlled. ONLY selected plants are intercrossed to obtain seed for the next cycle of selection. Expected genetic gain from selection of only female parent is one-half compared to expected genetic gain when both parents are selected.

But terms mass selection and phenotypic recurrent selection are sometimes used interchangeably and one would have to look at the breeding scheme for details in order to determine which method is being referred to.

Genotypic Vs. Phenotypic Recurrent Selection

The difference between genotypic and phenotypic recurrent selection is that Genotypic Recurrent Selection is selection **based on progeny performance** (combining ability), while Phenotypic Recurrent Selection is selection based on the **phenotype of the individual**.

Examples

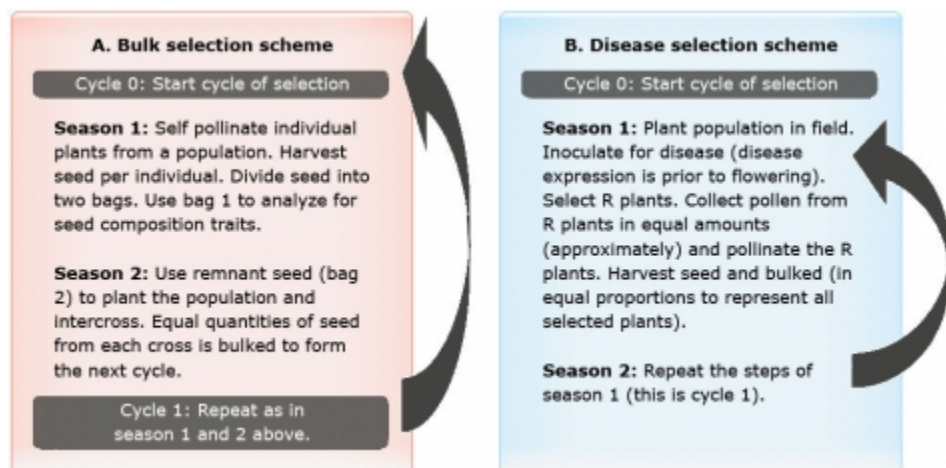


Fig. 9 Recurrent selection schemes for bulk method versus individual plant methods.

Phenotypic Recurrent Selection Issues

There are several problems with selecting individual plants in the field:

- Micro-environment variability doesn't permit assessing breeding value.
- Competition effect due to uneven planting.

Solutions to these problems include:

- Gridding designs (selecting plants within a grid)
- Not selecting plants that have missing neighbors

The generalized recurrent selection method consists of the following steps:

- development of a base population (for selection).
- evaluation of individuals from the population
- selection of superior individuals from the population
- intercrossing the selected individuals to form a new population.

Development of Base Population

A base population can be an existing population (for example a maize synthetic) which may not have been previously selected for your trait of interest.

More commonly, a base population will come from outstanding families from a recurrent selection program. It may also be created with elite inbred lines. Smaller number of inbred lines will ensure use of elite material that are similar morphologically, but inbreeding depression will be greater.

Superior inbred lines are identified based on their performance in multi-location tests and superior general combining ability (specific combining ability is not as important in the performance of OPV; it is most important if one is developing a hybrid cultivar).

These superior inbred lines are crossed using an appropriate mating design from among available designs (for example, diallel design).

Evaluation of Individuals

Table 1 Comparison of phenotypic and genotypic schemes in individual selection

Phenotypic	Genotypic
<ul style="list-style-type: none">• Evaluation of individual plants per se	<ul style="list-style-type: none">• Evaluation is based on the performance of the progeny of the individual
<ul style="list-style-type: none">• Assessment is very variable unless species can be clonally propagated	<ul style="list-style-type: none">• Progeny performance strategy allows for replicated, multi-location testing.
<ul style="list-style-type: none">• Not easy to control environmental variability	<ul style="list-style-type: none">• This provides a more accurate assessment of individual's breeding value
	<ul style="list-style-type: none">• Three types of progenies can be evaluated: self, full sib, or half sib

Progeny are produced by self-fertilizing the individuals (that are evaluated for selection).

Full-sib families are created by crossing the individuals to be evaluated in pairwise combinations. Since in each pairwise cross, both parents are common for that family, individuals of that family are full-sibs.

Half-sibs are formed by crossing the individuals to be evaluated to a common parent (which can be a population or an inbred line as a tester. Since all progeny have the tester as a common parent, they are half-sibs).

Population Improvement

Table 2 Methods in recurrent selection.

Intrapopulation improvement	Interpopulation improvement
Mass selection (with or without pollen control)	Reciprocal half sibs recurrent
Half-sib family	Reciprocal full sib Testcross
Full-sib family	
Selfed family	

Recurrent Phenotypic Selection

Steps include:

- Plant a population (space planting individuals to facilitate note taking on individual plants).
- Evaluate for trait of interest and identify the best individuals (higher heritability such as flowering time or morphological traits are suitable for this method).
- Harvest seed of the best individuals and reconstitute seed to form the next cycle of recurrent selection.
- In this example, pollen control can be exerted if the trait can be evaluated prior to flowering. Undesirables can be removed before they contribute pollen to the rest of population; and this ability to control parental pollen helps improve the response to selection.

Recurrent Half-Sib Selection

- Intra-population improvement method: cross the individuals in a population to a common tester (population per se, or inbred tester), evaluate the half-sib progeny of each plant, select the best individuals, and intercross the selected individuals.
- Main step is evaluation of individual's through their half-sib progeny. There are numerous variations within and among crops based on what is used as a tester (population vs inbred), parental control, intercrossing.
- Where possible, it is desirable to control both parents. This can be achieved by evaluating in one season and recombining in another generation (in winter nursery or second season). This necessitates an extra season but genetic gain per year will be higher. While the half-sib are being evaluated, the remnant seed of the individual needs to be kept as reserve so that this seed can be used if the individual is selected based on the half-sib performance to intermate and create material for the next cycle of selection.
- In maize, obtaining selfed and half-sib seed from the same plant can be accomplished by self pollinating the single ear on the individual to be tested and using pollen from that individual to pollinate several individuals of the tester (bulk of population per se, or inbred line). The ears on the tester, bulked together from that individual as pollen source, represent the half-sib family to be tested for that individual.
- Recombining selfed progeny will require three seasons: (1) selfing and crossing to the tester, (2) evaluation, and (3) intercrossing selfed progeny.

Recurrent Half-Sib Example

Female parent selected; population used as tester.

- Start with a random mating population
- Harvest ears of each plant (say, 200) Grow 200 half-sib progeny plots (with checks) at multiple locations (can be unreplicated or replicated). Traits of interest is yield (for example). At one location, grow in isolation – seed source for next cycle. At this location, select plants within a half-sib row. Other locations, use for testing.
- At location with isolation, grow the male rows (bulk seed of all half-sib families) adjacent to female half-sib rows. De-tassel the female rows.
- At location, where grown in isolation harvest ears from each selected plant by hand. Make selections to pick the best half-sib families. These ears will form the next cycle seed.
- Season 2, random mating of selected plants.
- Repeat steps

One can use an inbred line as tester instead of bulk seed of population used as male.

Recurrent Half-Sib Example

Female and male parent selected; population used as tester.

- Cycle 0 (intermate population)
- Harvest ears from each plant (selection may be performed)
- Divide the seed of half sib plants into two: part 1 for next season field testing, part 2 for remnant to reconstitute selected half-sibs.

Season 1: Each half sib (using part 1 seed) is a separate entry in replicated or unreplicated trials with 2 or more locations, with checks.

- Select superior half-sib families based on performance. These selections will be used in crossing.

Season 2: remnant seed (part 2 of seed bag) of selected individuals is used for intercrossing to form next cycle.

Cycle 1: Seasons 3 and 4 – repeat as above.

One can use an inbred line as tester instead of bulk seed of population used as male.

Recurrent Half-Sib (Testcross Progeny)

- Start with an intermated population
- Season 1: plants in an intermated population are selfed and pollen used for selfing and pollinating a tester.
- Season 2: testcross progeny are evaluated in replicated tests. Selections made to identify superior performing progenies.
- Season 3: selfed seed of selected families are used to form the next intermating cycle. Cycle is repeated as above.

Recurrent Full-Sib Process

Main steps are:

- Season 1: Make paired crosses between individuals in the population.
- Season 2: Evaluated the full-sib families in the field and identify the best families.
- Season 3: Recombine (intercross) the best families using remnant seed from the first season.

End of first year.

Start of second year:

- Season 4: Begin the second cycle with paired crosses between individuals in the population.

An advantage is the completion of one cycle per year. A disadvantage is less recombination between cycles of selection.

Recurrent Full-Sib Example

Start with an intermated population. Make selections.

- Season 1: paired crosses are made between pairs of selected plants in a population. Seed is divided into two parts: Part 1 is for field testing, and Part 2 is to reconstitute next cycle.
- Season 2: Part 1 seed used to plant field tests. Evaluate full-sib in field tests (single or multiple locations, unreplicated or replicated, with checks). Select superior families based on performance.
- Season 3: Part 2 seed used to intercross selected families. Intermated seed is used to form the next cycle.
- Cycle 2: Seasons 4, 5, 6.

Recurrent Selection Among Selfed Families

- Season 1: S_0 plants from the population are selfed to produce $S_{0:1}$ lines.
- Season 2: Evaluate the selfed progenies in field (for trait of interest).
- Season 3: Use the remnant S_1 seed from season 1 to intercross selected lines.

This completes cycle 1 and S_0 plants are obtained. The cycle is repeated as described above in season 4-6 for cycle 2, and so on.

Variation can include more than one generation of selfing if more seed is required for evaluation.

Reciprocal Recurrent Selection

Reciprocal recurrent selection (RRS), as a breeding method for open-pollinated crops was first proposed by Comstock et al. 1949 to take advantage of both additive and dominance genetic effects. In brief, plants from one population are mated to plants of another population, and selection of individuals for the next cycle of selection is based on the performance of progeny in hybrid combination. For this breeding method, each cycle requires one generation for selection of individuals and a second generation for intermating of selected individuals to produce materials for the next generation. RRS is a procedure to improve both the general and specific combining ability of two populations simultaneously, and steps involved are as below:

- Plants are selected in each of two populations
- Plants of population#1 are selfed and outcrossed as the tester to the selected plants in population#2 to generate test cross progeny.
- Plants of population#2 are selfed and outcrossed as the tester to the selected plants in population#1.
- The resulting test cross progenies are evaluate in each season. Superior plants are identified based on their test cross performance. Selfed seed from these selected plants are used to intercross within each population to generate materials for the next generation.
- Cycle is repeated.

Maize OPV

Development of a Maize OPV

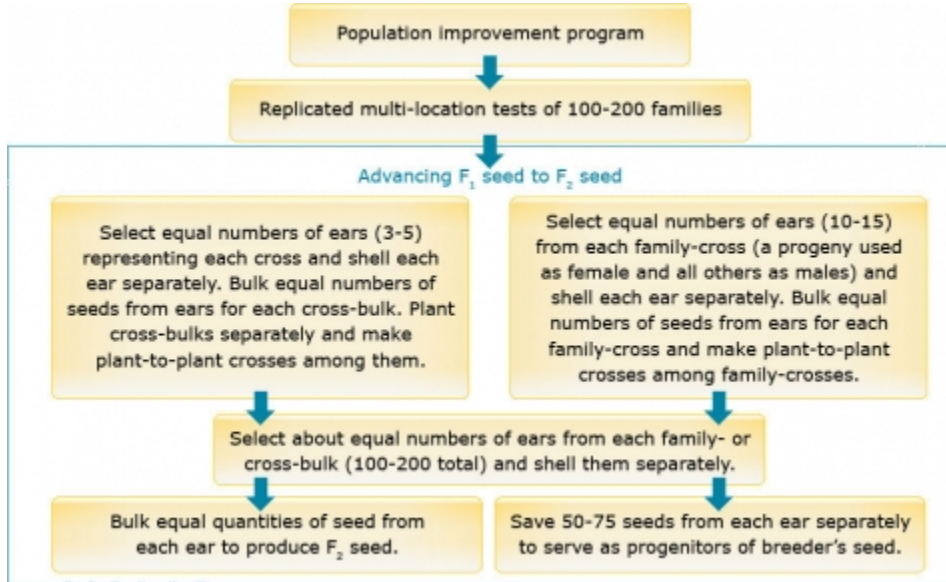


Fig. 10 Flow chart of development of an OPV of maize. Adapted from The Maize Program, 1999.

Maize OPV Cultivar Evaluation

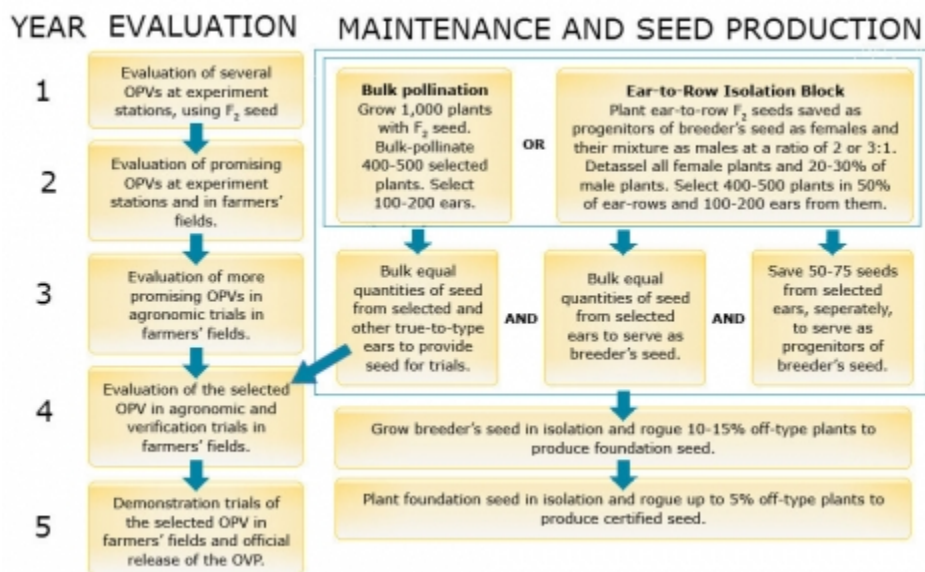


Fig. 11 Flow chart of cultivar evaluation, maintenance, and seed production of maize.

OPV Advantages and Disadvantages

Table 3 OPV advantages and disadvantages.

ADVANTAGES	DISADVANTAGES
<ul style="list-style-type: none">• Seed can be re-cycled (if grown in isolation or middle field harvested without a significant yield reduction due to inbreeding depression)	<ul style="list-style-type: none">• Yields lower than hybrids
<ul style="list-style-type: none">• Can have much more broader adaptability compared to hybrids (that are developed for targeted areas)	<ul style="list-style-type: none">• Is not comparable to hybrids in areas where land is fertile and inputs are available to maximize yield
<ul style="list-style-type: none">• May be less costly than hybrid	<ul style="list-style-type: none">• Plants are less uniform
<ul style="list-style-type: none">• May require less inputs than hybrids	<ul style="list-style-type: none">• Seed needs to be harvested properly to use for next year, and even then there will be a yield reduction.
<ul style="list-style-type: none">• OPV may be more accessible in areas where no hybrids are available or seed availability channels are poor	

Clonal Cultivar Methods

Since each clone breeds true (i.e., no gene segregation because no sexual recombination), breeding programs can evaluate a clone in several different tests simultaneously (field testing, disease nursery etc.). In clonal crop breeding, each cross produces unique and distinct F_1 seed (true seed). True seed is transplanted into field testing and selection commences to identify which F_1 of F_1 's are suitable for cultivar release. Step-wise reduction process is used to discard undesirable F_1 clones each testing season (remember, clones can be propagated for more extensive testing once smaller number of desirable clones are identified. Below is an example of sugarcane cultivar CP 03-1912 developed in Florida.

Table 4 Summary of process followed in the release of sugarcane cultivar CP 03-1912 in Florida. Data from Gilbert et al., 2011.

Year	Month	Stage and activity completed	No. genotypes in stage	Locations
2000	Dec	Cross made at USDA-ARS sugarcane field station	–	Canal Point, FL
2002	May	Germinated true seed transplanted into field (seedlings)	100,000	Canal Point, FL
2003	Jan	Advanced from plant-cane seedlings to stage 1	15,000	Canal Point, FL
2003	Sep	Assigned name CP 03-1912 in stage 1	15,000	Canal Point, FL
2003	Nov	Advanced from plant cane stage 1 to stage 2	1,496	Canal Point, FL

Year	Month	Stage and activity completed	No. genotypes in stage	Locations
2004	Nov-Dec	Advanced from plant cane stage 2 to stage 3	135	Four farms in Florida
2006	Nov-Dec	Advanced from plant cane stage 3 to stage 4 sand soils	13	Four farms in Florida
2011	Feb	Cultivar release	1	-

Approximately 10% culling rate was practiced in each season after 2003. As seasons advance, clones are grown in replicated yield trials at several locations and comparisons with standard checks is made to identify which clones to advance to the next stage of testing.

Synthetic Cultivar

Synthetic cultivars are formed by using clones of inbred lines in pre-determined proportions for released to farmers. Farmers can use a synthetic for several generations (as open-pollinated population) but once inbreeding depression causes yield reduction, farmers need to use seed from the breeding institution or company. Therefore synthetics are reconstituted regularly by the breeder. Maize is an example where synthetics have been developed. In crops with self-incompatibility, synthetics are the preferred types of cultivars as the method exploits heterosis for a few generations.

Clones or inbred lines used in the formation of synthetic are chosen on the basis of their general combining ability. Crossing is made to ensure random pollination allowing gametes of each component (clone of inbred line) to be equally represented.

Recommended Readings

- Acquaah G. 2007. Principles of plant genetics and breeding Wiley-Blackwell, Malden.
- Sleper, D.A., and J.M. Poehlman. 2006. Breeding Field Crops, 5th Edition. Wiley-Blackwell. ISBN: 978-0-8138-2428-4
- Setimela, P.S., and P. Kosina. (eds). 2006. Strategies for Strengthening and Scaling up Community-based Seed Production. Mexico, D.F.: CIMMYT. Read Chapter 1. AVAILABLE Online: <http://repository.cimmyt.org/xmlui/bitstream/handle/10883/791/89218.pdf?sequence=1>

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- Canola Council of Canada. 2014. Canola varieties. <http://www.canolacouncil.org/canola-encyclopedia/crop-establishment/canola-performance-tool-variety-comparisons/>
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- Gilbert et al. 2011. Registration of 'CP 03-1912' sugarcane. JPR 5(3): 319-324.
- International Rice Research Institute. 2006. Molecular breeding, Lesson 1: Marker assisted breeding for rice improvement. http://www.knowledgebank.irri.org/ricebreedingcourse/bodydefault.htm#Marker_assisted_breeding.htm

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Crop Improvement Breeding Methods Author: Asheesh Singh, and Arti Singh (ISU)

Multimedia Developers: Gretchen Anderson, Todd Hartnell, and Andy Rohrback (ISU)

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