Conventional Breeding Approaches

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This chapter presents an extensive review of traditional plant breeding approaches utilized in improvement of crops with respect to self-pollinated and cross-pollinated crops. It covers key methodologies, including conventional breeding methods like pure-line selection, mass selection, and pedigree methods, as well as more advanced strategies such as recurrent selection, hybridization, and backcross methods separately. The conventional approaches emphasize the selection of phenotypically, superior plants to enhance traits such as yield, resistance to diseases, and adaptability to abiotic conditions, while maintaining genetic diversity. The document also explores the use of hybridization to exploit heterosis, the development of synthetic varieties, and the application of recurrent selection for specific and general combining ability. Furthermore, it discusses the limitations, advantages, and practical applications of each method, offering insights into their effectiveness in addressing contemporary agricultural challenges such as climate change and pest resistance. The detailed procedures, achievements, and potential for further improvement in crop varieties are highlighted, underscoring the critical role of these breeding strategies in ensuring sustainable agriculture and food security.

Keywords: *Pure-Line Selection, Pedigree method, Bulk method, back cross method.*

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Introduction

Conventional breeding capitalizes on natural genetic diversity through techniques such as cross-pollination and selective breeding. This method involves hybridization of carefully selected parents, incorporating related species or wild relatives, to transmit desired traits to subsequent generations without violating mendelian inheritance principles (Allard, 1961). Selection criteria are primarily based on phenotypic characteristics, guided by extensive observation and empirical knowledge of cultivators/ crop breeders. Subsequently, selected plants undergo rigorous testing before their release as commercially viable varieties, a process that typically spans a decade or longer (Bharti & Chimata, 2019). The overarching goal is to amalgamate advantageous traits from diverse individuals within a species, thereby fostering genetic variability and enhancing adaptability to varying environmental conditions. By bolstering traits such as yield potential, disease resistance, and overall resilience, conventional breeding remains indispensable for sustainable agriculture, ensuring food security amidst contemporary challenges such as climate change and pest pressures. (Sashi Lamichhane & Sapana Thapa, 2022).

Methods for self-pollinated crops

Pure-line selection

- Pure line selection is a process in plant breeding where the best individual plant progeny is identified and isolated from a single self-pollinated homozygous plant.
- The resulting pure line consists of genetically identical offspring.
- Selection is artificial and aims to improve yield and quality.

Theory of pure-line selection

- Developed in Sweden during the mid-19th century, where the concept of pure lines gained prominence. Danish biologist Johannsen explained the genetic basis of pure lines in 1903.
- A pure line is the progeny of a single self-pollinated homozygous plant.
- The method involves:
    - Identifying the best plant within a population.
    - Isolating and propagating its progeny.
    - Repeating this process to create a genetically uniform line.

Procedure

1. First season: Selection of superior plants: Choose 200-3000 plants based on phenotypical performance.

2. Second season: Individual plant progenies:
- Grow progenies (offspring) from the selected plants.
- Observe their growth, yield, and other relevant traits.
- Reject undesirable progenies based on poor performance.

3. Third season: Preliminary yield trials:
- Plant the selected progenies in preliminary yield trials.
- Evaluate their yield potential, disease resistance, and quality.
- Reject inferior progenies which does not meet the desired criteria.

4. Fourth to sixth seasons: Replicated yield trials:
- Conduct replicated yield trials at multiple locations.
- Compare the performance of the selected progenies with suitable checks (standard varieties).
- Assess disease resistance, quality, and other relevant factors.

- Repeat the trials over multiple seasons to ensure consistency.

5. Seventh season: the best superior line is released as a new variety and initiate seed multiplication and distribution.

Advantages

- Ensures genetic uniformity, hence easily identify in seed certification programmes.
- It achieves maximum improvement in an original variety.
- Useful for self-pollinated crops.

Limitations

- Depletes genetic variability.
- Not effective for characters influenced by environmental factors.
- The variety cannot have wider adaptation and stability.

Applications

- This is used for local varietal improvement, which have greater variability. Example*:* In wheat NP4 and NP5, in linseed NP11 and NP12, in cowpea, T1, in okra pusa savani bhindi.
- This is used for improvement of introduced varieties. Example*:* Shining Mung 1 from from kulu type 1 variety in mungbean and kalyan sona in wheat.
- This is applied in old pure line varietal improvement. Example*:* Chafa from No. 816 in gram, Syama from Kalimoonch 64 in rice, and CO2, CO3, Pusa Baisakhi in mung bean.
- Pure line selection is used in selection for a new character in a variety. Example*:* In 1926, jowar crop, where dwarf yellow milo variety was not bred for root rot resistance and spread in Kansas, USA. Hence, resistant plants were selected from infested field to develop a new variety resistant to root rot by this method.
- Pure line method is also helpful in selecting plants in segregating generations of a cross in other methods like pedigree, back cross and bulk methods.

Achievements

In the realm of plant breeding, pure-line selection has yielded remarkable results. Notable examples include Mtu1, Patni6, and T22 in rice, which exhibit improved yield and disease resistance. Barley varieties, C50 and C251 were developed through pure-line selection, are high-yielding and uniform. Rice varieties like, MTU7, MTU2, MTU 1, and T29 showcase desirable traits. In maize, Jaunpur local, Tinpakhia, and Basri Pearl stand out, although records are scarce. Additionally, Gurgaon brown sarson in mustard; T1 and B1 in mungbean crop; Gadag 1 and Combodia Coimbatore 2 in cotton; NP7, NP 63 and NP28 in tobacco and RSI in sorghum exemplify the success of this method. (Faheem Akhtar et al., 2023). More examples can be found in Singh, B.D. book, pg. 267.

Mass selection

Mass selection is the earlier method in crop improvement strategies. In this approach, individual plants are carefully chosen based on observable characteristics (phenotype) from a mixed population. The selected plants' seeds are then mixed (bulk-seeded) to grow next generation. The primary objectives of selection include:

- Improvement of the local varieties: In self-pollinated crops, mass selection helps eliminate poor-quality plants from local varieties, resulting in more uniform performance.
- Purification of existing pure-line varieties: Over time, pure line varieties can become variable due to mechanical mixtures, natural hybridization, and mutations. Regular mass selection helps to maintain the purity of these varieties.
- Production of new varieties from heterogeneous local land races: By increasing the frequency of superior genotypes, mass selection alters the population's characteristics. Cross-pollinated crops avoid excessive inbreeding through this method.

The mass selection process involves several steps:

First season: Select a large number (200-2000) of plants based on desirable traits (Example: vigor, disease resistance). Composite their seeds together.

Second season: Plant the composite seeds in the preliminary yield trials alongside standard varieties to assess any improvement.

Third to sixth season: Evaluate the composite seeds in co-ordinated yield trials across different locations of the same agro-climatic zone.

Seventh season: The genotype which perform outstanding in all trials will be released for cultivation.

Advantages

- Wide adaptability: Varieties developed through mass selection exhibit broad adaptation and stability. Their genetic base is wider, providing better buffering capacity against environmental changes.
- Cost-effective and simple: Mass selection is a rapid, straightforward, and inexpensive plant-breeding procedure.
- Genetic variability retention: Mass-selected varieties retain considerable genetic variability, which is valuable for improving land races.

Limitations

- Variation and uniformity: Mass-selected varieties exhibit more phenotypic variation compared to pure-line varieties. Their seed quality is less uniform.
- Homozygosity testing: To ensure homozygosity, progeny testing is necessary. Otherwise, selected types may segregate in the next generation.
- Less improvement: Mass selection typically results in less improvement compared to pure-line selection.
- Compared to pure lines, these varieties are difficult to identify in seed certification programmes.

- Mass selection does not create new variability.

Applications

- Limited use: Mass selection is less commonly used for self-pollinated crops. It finds more application in cross-pollinated species.
- It's generally not suitable for handling segregating populations derived from hybridization.

Achievements

TMV 2 and TMV 1 in Groundnut; T 22 and RSI (Raj) in sorghum; K-122 in potato; Tinpakhia, basri and Jaunpur in maize; pusa moti, bajri-28-25, bichpuri local and bajra -207 in pearl millet; gurgaon brown sarson in mustard; combodian cotton, dodahatti local and dharwar American in cotton *etc.* developed by mass selection.

Pedigree method

In pedigree methods, from F_2 generation onwards, individual plants are selected and their progenies are evaluated. In entire process, proper records of the ancestry of selected plants are maintained, which denotes parent to offspring relationships, called pedigree record. This method is widely used for improving self-pollinated crops. It focuses on desirable traits and ensures homozygosity in the resulting varieties. This method was first outlined in 1927 by Love.

Procedure

1. First season (Crossing the Parents):
   - Select parents based on genetic diversity. Their choice significantly impacts the success of the breeding program.
   - Cross the chosen parents to obtain the F_1 generation.

2. Second season (F_1 Generation):
   - Space-plant the F_1 individuals (10-30 seeds or more) to ensure ample F_2 seed production.
   - Good spacing allows better growth, increased tillering, and higher seed yield.

3. Third season (F_2 Generation):
   - Raise approximately 2000-10,000 plants in the F_2 generation.
   - Select about 200-500 plants with desirable major genes (*Example:* disease resistance) and other desired traits.
   - Keep the seeds from each selected plant separately for the next generation.

4. Fourth season (F_3 Generation):
   - Individual plant progenies should be planted in rows with good spacing.
   - Maintain progeny rows with 30-100 plants per row.
   - Superior plants should be selected from superior progenies within and between progeny rows.

5. Fifth to Seventh Season (F_4 to F_6 Generation): same as F_3 generation.

- In F_6 generation, emphasize selection of progenies rather than individual plants and harvest in bulks as they would have attained homozygosity almost.
- Shift focus toward selecting entire progeny lines.

6. Eighth season (F_7 generation):
    - The superior progenies should be evaluated for desired yield and related characters in preliminary yield trials in replications.
7. Ninth to Eleventh Seasons (F_8 to F_{10} generation): The selected lines from preliminary trials should be subjected to test in coordinated trials in multiple locations for three seasons.

8. Twelfth Season (F_{11} generation): the superior progeny should be released as a new variety. It should be multiplied and distributed to farmers.
    - During this entire period, maintain proper pedigree records to avoid selecting closely related lines.
    - Achieve homozygosity and stability in a new cultivar.

Advantages

- Efficiency: The pedigree method takes less time compared to the bulk method, making it suitable for individual plant selection after hybridization.
- Transgressive segregants: It provides a chance to recover transgressive segregants—individuals with traits beyond the parental range.
- Time frame: Developing a new variety using the pedigree method typically takes 14-15 seasons, which is shorter than the bulk method (15-16 seasons).
- Inheritance insights: Pedigree records reveal information about the inheritance of qualitative characters that other breeding methods may not capture.
- It provides best opportunity to the breeder to use his skill in selection of plants.
- Progenies with defects can be eliminated at early stages.

Limitations

- Labor-intensive: Maintaining pedigree records is time-consuming and requires meticulous effort.
- Reduced genetic variation: As individual plant selection progresses through generations, genetic variation available for selection decreases.
- Ineffective yield selection: Selecting for yield or other characters in F_2 and F_3 generations may not yield optimal results.
- Skill dependency: Successful implementation of this method relies heavily on the breeder's expertise and skill.
- There is no opportunity for the natural selection.

Applications

- Pedigree method is used for selection in segregating generations of self-pollinated crops.
- This method is used to rectify the defects in an existing variety (Combination breeding).
- Pedigree method also helpful in selecting new recombinants *i.e.* transgressive segregants are recovered (transgressive breeding).

Achievements

These cultivated varieties represent significant advancements in quality, disease resistance, and yield potential. Notably, the pedigree method played a pivotal role in their development. For instance, wheat varieties such as K65, WL711, K68, NP52, NP80-5, and NP120 emerged through the pedigree approach (Briggs & Shebeski, 1971). Among these, K65—a tall wheat cultivar—was specifically recommended for rainfed conditions. In rice breeding, both Taichung Native 1 and IR8 have directly or indirectly contributed to the creation of numerous high-yielding cultivars. The exceptional rice types Jaya and Padma originated from the TN1 x T141 cross. Padma, characterized by finer grains and a shorter duration, stands out in this lineage. Furthermore, the pedigree method was instrumental in developing other notable rice varieties, including Bala, Kaveri, Karuna, Krishna, Ratna, and Sabarmati. However, it's essential to acknowledge that red blight posed challenges during the pureline selection of the Gadag 1 which is *Gossypium hirsutum* variety from the Dharwar-American variety.

Bulk method

This was first used in 1908 by Nilsson-Ehle. In bulk method, F_2 and the subsequent generations are harvested in bulks to raise the next generation till the genotypes attain the homozygosity. So, this method is also named as, mass or population method.

Applications

- Isolation of homozygous lines: The population in F_6 or F_7 bulks, it is almost homozygous and homogeneous. So, development of homozygous lines can be done with less efforts and cost. The best lines are selected and evaluated in yield trials as in pedigree method.
- Waiting for opportunity of selection: Selection is based on suitable environmental conditions for the traits *viz*., disease resistance, cold/ drought stress *etc*. Hence, segregating material has to be carried until such environments commenced and avoid artificial selection. This is also called as mass-pedigree method of Harlan.
- Opportunity of natural selection: this method allows natural selection to change the genetic frequencies of population. It is also named as evolutionary method of breeding suggested by Suneson.

Procedure

- First Season (Hybridization): Based on the objective, the selected parents are hybridized to produce simple or complex cross.
- F_1 generation: F_1 generation, usually larger than 20 plants are space planted and harvested in bulk.
- $F_2 – F_6$ generation: From F_2 to F_6 generation, plants are space planted at commercial seed rate and bulk harvested. During this period, natural selection alters the genetic composition in the population. Generally, 30,000 to 50,000 plants should be maintained in each generation.
- F_7 generation: The selected plants are space planted. 1000-5000 phenotypically superior plants are harvested separately.
- F_8 generation: Individual plant progenies are raised in rows, which are mostly homozygous. 100-300 superior plant progenies are harvested in bulk.

- F_9 generation: The PYT (preliminary yield trial) is conducted with commercial checks. Progenies are evaluated for the desirable characters. 2-5 outstanding lines superior to the check would be advanced to the co-ordinated yield trials.
- F_{10}- F_{12} generations: The selected lines have to be evaluated over several locations in co-ordinated yield trials. If the line is superior over the check, then the line should be released as a new variety,
- F_{13} generation: Seed should be multiplied and distributed as commercial variety.

Advantages

- Higher the frequencies of superior genotypes due to the involvement of natural selection.
- Higher the chance of isolation of transgressive segregants compared to the pedigree method.
- Selection for quantitative traits is more effective and suited for small grain crops.
- Simple and inexpensive method, that allows breeder to focus on other breeding programs.

Limitations

- Involving natural selection is more time taken than in pedigree method.
- There is less opportunity to exercise skill for a breeder.
- Cannot obtain the information on inheritance of character.
- Sometimes, agronomically desirable types may be eliminated by natural selection.
- To advance the generations, off-season crops and green house facilities cannot be used.

Single seed descent method (SSD)

In 1941, C.H. Goulden proposed this method. It is the modification of bulk method. The major objective of SSD method is rapid advancement of generations. To obtain recombinant inbred lines from the selected cross in less time, it will be helpful. In this method, a single seed from each of the plant from F_2 generation are bulked to raise the next generation. In the F_5/F_6 generation, individual plants should be selected and plant progenies are to be grown in the next generation. Superior progeny rows are harvested in bulk to conduct yield trials in F_7/F_8 and co-ordinated trials are initiated in F_8/F_9.

Advantages

- Advancement of the generations with maximum possible speed in the conventional breeding.
- It requires very little space, cost, efforts and labour
- This makes use of greenhouse and off-season nursery facilities.

Limitations

- There is no means of selection in all the segregating generations.
- In each generation, the population size becomes smaller due to poor germination, death of plant and other factors.

Back cross method

A backcross involves crossing a hybrid (either the F_1 generation or a segregating generation) with one of its parents. Subsequently, the progeny resulting from this cross are repeatedly backcrossed to the same parent as the F_1 hybrid (Aleksoski, 2018). The key requirements for successful backcrossing include:

- **Recurrent parent selection:** Choose a suitable recurrent parent—one that possesses desirable traits but lacks a specific intense character found in the hybrid.
- **Donor parent:** Select an appropriate donor parent that carries the desired trait to be transferred. This trait should exhibit high heritability and be governed by one or a few genes.
- **Multiple backcrosses:** Conduct a sufficient number of backcrosses to ensure stable inheritance of the desired trait.

Procedure

The backcross method is a valuable breeding technique used to transfer specific traits from a donor parent to a recurrent parent.

When dealing with dominant gene expression, the procedure involves the following steps:

1. Hybridization (First Season): Cross the donor parent (which carries the dominant allele, R) with the recurrent parent (which carries the recessive allele, r).

2. F_1 Backcrossing (Second Season): Obtain the F_1 generation, which is heterozygous (Rr) for the trait of interest and should be backcrossed with the recurrent parent (rr).

3. Subsequent Generations (BC_1, BC_2 *etc*. Third to Tenth Seasons):

   - The resulting BC_1 progeny will be susceptible homozygous recessive (rr) and resistant heterozygous (Rr) equally, and reject 'rr' progeny and select resistant (Rr) plants.
   - Continue backcrossing 'Rr' to the recurrent parent (rr) upto BC_5 or BC_6 generation, where 99% genes would be transferred from recurrent parent along with desired gene from donor parent. Selected plants should be selfed and harvest separately, gives BC_6F_2 seeds.
   - Grow individual plant progenies from BC_6F_2 seeds and resistant plants should be again selfed and harvest the seed separately, forms BC_6F_3 seeds.

4. Evaluation and Selection (Eleventh Season): Individual plant progenies should be grow from BC_6F_3 seeds. Evaluate the performance of the selected lines in replicated yield trials using recurrent parent as a check. As the developed variety is similar to recurrent parent except in resistance, the detailed yield trials are not required.

5. Seed multiplication and distribution (Twelfth Season): Multiply and distribute the seeds of the improved lines.

When dealing with recessive gene expression, the procedure involves the following steps:

1. Hybridization (First Season): Cross the donor parent (which carries the recessive allele, rr) with the susceptible recurrent parent (which carries the dominant allele, RR).

2. F_1 backcrossing (Second Season): Obtain the F_1 generation, which is heterozygous (Rr). And back crossed with recurrent parent (RR).
3. Selfing (Third season): In the generated BC_1 progeny, reject (RR) susceptible plants; and selected resistant plants (Rr) should be selfed to produce BC_1F_2. Select only resistant plants (rr).

4. Back crossing (4^{th} – 5^{th} season): Back crossed rr plants with recurrent parent (RR) for two seasons gives BC_2 and BC_3 generation.

5. Selfing (6^{th} season): In the generated BC_1 progeny, reject 'RR'; and 'Rr' should be selfed to produce BC_3F_2. Select only resistant plants (rr).

6. Back crossing (7^{th} - 8^{th} season): Back crossed rr plants with recurrent parent (RR) for two seasons gives BC_4 and BC_5 generations.

7. Selfing (9^{th} to Tenth Season): In the generated BC_5 progeny, resistant plants should be selfed for two years to produce BC_5F_2 and then BC_5F_3. In BC_5F_3, grow individual plant progenies and select resistant plants with similar characters of recurrent parent. Selfed seeds are harvested and bulked.

8. Yield trials (11^{th} Season): Evaluate the performance of the selected lines in replicated yield trials using recurrent parent as a check. As the developed variety is similar to recurrent parent except in resistance, the detailed yield trials are not required.

9. Seed multiplication and distribution (12^{th} Season): Multiply and distribute the seeds of the improved lines.

Advantages

- Trait transfer: Backcrossing allows efficient transfer of a specific trait from a donor parent to recurrent parent.
- Genetic background: It maintains the genetic background of the recurrent parent, ensuring stability and adaptation.
- Speed: Backcrossing is relatively faster than other breeding methods, especially when targeting a single trait.
- Precision: Breeders can focus on a particular gene or a few genes of interest.

Limitations

- Reduced genetic diversity: Repeated backcrossing narrows genetic diversity, potentially limiting adaptability.
- Labor-intensive: Conducting multiple backcrosses demands significant effort.
- Risk of linkage drag: Undesirable genes linked to the target gene may inadvertently transfer.
- Inefficient for polygenic traits: Backcrossing is less effective for traits controlled by multiple genes.

Applications

- Back cross method is used to transfer of simple and heritable characters, which governed by one or two genes like resistance to diseases between the varieties. But sometimes, linkage drag is the problem.
- This method is used to transfer of quantitative characters between varieties like plant height, earliness, seed shape and size, which are having high heritability.
- This technique is used to transfer of simple and heritable traits between species. Example: Leaf and stem rust resistance to *Triticum aestivum* from *T. timopheevii*, *T. monococcum.*
- This back cross method is used to transfer of cytoplasm/ male sterility from one species to other species. *Example:* Cytoplasmic male sterility from *Triticum timopheevii* to *Triticum aestivum.*
- This method also cane used to develop transgressive segregants with some modifications like increasing no. of recurrent parents or no. of back crosses.
- Through back cross method, near isogenic lines can be developed, which can be used as mapping population for many recent studies.
- Back cross method is also helpful in converting the germplasm. Example: Photo-insensitivity in sorghum crop.

Achievements

- Rust resistance in wheat (Kalyan Sona): Rust resistance was successfully transferred to the wheat variety Kalyan Sona from diverse sources such as Robin, HS 19, and Bluebird.
- Downy mildew resistance in male sterile lines (Tift 23A): Tift 23A was used in backcross programs with resistant lines from India and Africa. This effort led to the development of downy mildew-resistant male sterile lines, including MS521 and MS541.
- *Gossypium herbaceum* varieties: Backcrossing played a crucial role in enhancing the genetic makeup of *Gossypium herbaceum* varieties, including Vijapla, Vijay & Digvijay.

Breeding methods for cross pollinated crops

Recurrent selections

In 1919, Hayes and Garber introduced the concept of recurrent selection, which was also independently proposed by East and Jones in 1920. During the 1940s, particularly after 1945, Hull advocated for the effectiveness of recurrent selection in enhancing specific combining ability. This method involves crossing an inbred with a heterozygous recurrent parent, thereby maintaining genetic diversity and increasing the frequency of desirable traits. This method is mainly used for cross-pollinated crops (Khadr, 1964). Initially developed for maize, recurrent selection has since been adapted for other cross-pollinated crops such as rice, millet, wheat, and soybeans (Ramya *et al.*, 2016). According to Luckett and Halloran (2017), there are three main types of recurrent selection: (1) Simple Recurrent Selection, (2) Recurrent Selection for Combining Ability, and (3) Reciprocal Recurrent Selection.

1) Simple recurrent selection

In the first season, number of superior plants are selected based on their phenotype and subjected to self-pollination.

In the second season, the self-pollinated seeds from these selected plants are cultivated in separate rows. These plants are then manually intermated in all possible combinations, and an equal quantity of seed from each cross is collected to establish the next generation. This process constitutes the original selection cycle. From this composited population, superior plants are once again selected, and the cycle is repeated. This sequence of selecting superior plants and repeating the cycle continues, forming the first recurrent cycle, and is repeated until no further improvement is observed between the inter-crossed parents and the selected progenies.

Advantages

- This method increases the frequency of desirable genes within a population
- It is particularly suitable for improving traits with high heritability. Additionally,
- It maintains genetic variability.

2) Recurrent Selection for combining ability

a) Recurrent selection for general combining ability (RSGCA) was suggested by Jenkins in 1935 for the development of synthetic varieties from inbreds in cross pollinated crops. RSGCA involves crossing selected plants with a broad genetic base tester strain *i.e.* a synthetic variety, open pollinated variety or segregating population. The selection is based on early progeny testing of these crosses.

- First season: From source population (any population with broad genetic base), most desirable outstanding lines should be selected based on phenotype. Each line has to be selfed and also crossed as males with randomly selected plants from tester population as females. The selfed seed and crossed seed are collected separately.
- Second season: Crossed seed should be grown in replicated yield trial and record for superior progenies.
- Third season: Selfed seeds (of those plants which produced superior progenies in second season) should be raised in separate progeny rows, in a crossing block and allow for intermating in all combinations. Equal quantity of seed from all inter-crosses should be collected and composited to raise the next generation. This constitutes original cycle of selection.
- Fourth season: The composited seed is planted as the source population. Phenotypically desired plants should be selected and repeat the operations of first season.
- Fifth season: Second season operations are repeated.
- Sixth season: Third season operations repeated, which completes first recurrent selection cycle. This will be continued for several cycles until no further improvement is found between inter-crossed parents and selected progenies.

Advantages

- It is effective in changing GCA in the direction of selection.
- It is effective in increasing the yielding ability of the end population, which is identical to synthetic variety.
- It can be used to accumulate genes for superior GCA, so that, inbreds with high GCA can be isolated after a few cycles.

b) Recurrent selection for specific combining ability (RSSCA) was proposed in 1945 by Hull. In RSGCA, the tester is open pollinated variety, whereas, in RSSCA, tester is an outstanding inbred or parent of a hybrid. The entire procedure is similar as RSGCA.

3) Reciprocal RECURRENT Selection (RRS): This was proposed in 1949 by Comstock, Robinson and Harvey. In RRS, two populations (say A and B) can be improved, each serves as tester for the plants selected from other population.

- First Season: Phenotypically superior plants should be selected in both populations. All selected plants are selfed and also crossed with the selected plants of other population and harvested the selfed and crossed seed separately.
- Second Season: Crossed seed of A x B in one replicated trial and B x A seed in another replicated trial should be tested to identify superior progenies.
- Third Season: Selfed seed from the plants which produced superior progenies in second season replicated trials, should be raised in individual plant- progeny rows in two separate blocks. Within each block, allow for intermating in all possible combinations and collected seed in equal quantity from each cross. This completes the original selection cycle.
- Fourth Season: The composited seed from separate blocks is served as source population for next cycle. First season operations are repeated.
- Fifth Season: Second season operations are repeated.
- Sixth Season: Third season operations are repeated. This completes first recurrent selection cycle. This will be continued if desired, for further cycles.

Advantages

- Useful for development of a synthetic variety with high GCA and SCA.
- Useful for isolation of inbred lines and can be used to produce single and double cross hybrids.

Comparisons of recurrent selections: In theoretical grounds,

- RRS and RSGCA methods will be effective, if dominance is incomplete.
- If dominance is complete, all recurrent selections are effective.
- In case of over dominance, RRS and RSSCA is effective.
- In the presence of epistasis, linkage disequilibrium and multiple alleles, RRS is more effective. (Singh, 2004)

Hybridization

Population improvement through recurrent selections, progeny testing, mass selections *etc.* aim at keeping inbreeding depression low but efforts to exploit heterosis is rarely made. This can be achieved in cross pollinated crops by hybridization to develop hybrids and synthetics, and composites etc. Hybrid varieties are the progeny of a cross between two inbreds/ pure lines/ clones or other two genetically similar populations. An inbred is homozygous line, developed through continuous selfing of a cross-pollinated crop. Shull suggested the inbred development from selfing of an open pollinated variety in 1909. In 1912 East and Hayes proposed the adoption of heterosis breeding as an alternate breeding method for cross pollinated crops. double cross (involving four parents or cross of two single cross hybrids) method was proposed in 1918 by Jones to overcome the germination difficulties and cost in single cross hybrids. First commercial variety (Burr Learning Dent) was released in 1922. The significant landmark for hybridization is the development of male sterility or cytoplasmic genetic male sterility (CGMS) *i.e.* in 1938, Texas CMS was identified in maize and commercially utilized in hybrid development during 1960s, which made single cross hybrids more profitable and replaces double cross hybrids.

The hybridization procedure involved three steps:

1. Inbred development
2. Inbreds evaluation and,
3. Hybrid seed production

1) Inbreds development: Inbreds are developed from genetically variable population called source population through continuous inbreeding. This source population is generally open pollinated variety, synthetic or nay other variable populations. The procedure involved is,

- **First season:** A number of superior phenotypes are selected from a source population and selfed (S_1). These lines can be selected based on phenotypical performance or GCA estimates through early testing of their test cross progeny. Early testing was proposed by Jenkins in 1935. This means testing can be done during first selfed generation (S_1) or in source population (S_0). The selected lines from $S_{0,}$ S_1 or S_2 should be selfed and crossed with a tester having broad genetic base. The second step is growing individual plant progenies from selfed seed and in replicated yield trial with test crossed seed. The procedure for testing GCA is similar to recurrent selection for GCA (RSGCA). The superior progenies identified in replicated yield trial and use their selfed seed for next generation. Selection based on test cross progeny performance is effective to improve GCA of inbreds.

- **Second season:** Selfed seed of selected plants (based on testcross progeny performance) are space planted and allow for selfing (S_2).

- **Third to sixth season:** selected plants selfed until plant progenies become homogeneous and homozygous after 5-6 generations of selfing (s_6).

- **seventh season:** Inbreds can be maintained by sib-pollination or selfing and growing in ear-to row progenies to eliminate further variation in inbred varieties.

The inbreds characters can be improved by adopting several methods like, pedigree selection, back cross methods, convergent method (F_1 is back crossed to two parental inbreds separately to improve both the parents), gamete selection (F_1 is crossed with tester), soma clonal hybridization (production of cybrids), soma-clonal variation (invitro culture) and genetic engineering *etc.*

2) Inbred evaluation: Inbreds can be evaluated using following four practices.

- Phenotypic evaluation: It is highly effective for improving the characters having high heritability and high GCA. This will eliminate inferior and weak inbreds.

- Top cross test: Performance of top cross (inbred cross with tester having broad genetic base) progeny provides a reliable measure for GCA estimates of an inbred. Select the inbreds having high GCA.
- Evaluation of Single crosses: Single cross evaluation provides information about superior single cross combinations. The inbreds selected after top cross test are intermated in all possible combinations to produce single crosses. These single crosses are evaluated in replicated yield trials over locations and seasons. Single crosses with an outstanding performance are selected and released commercially.
- Predicted performance of double cross combinations: This was proposed in 1934 by Jenkins. The predicted performance of any double cross is the average performance of the four non-parental single crosses involving four parental inbreds.

Example: The performance of double cross (A x C) x (B x D) can be predicted based on the performance of non-parental single crosses *viz.,* A x B, A x D, B x C and C x D, but not involved the parental crosses A x C and B x D.

3) Production of hybrid seed: This requires two operations; emasculation and pollination. Male sterility and self-incompatibility offer a way for genetic emasculation and reduces the cost of emasculation during hybrid seed production. There are several ways for emasculation. *i.e*. genetic male sterility, cytoplasmic male sterility, cytoplasmic- genetic male sterility, Self-incompatibility, pistillate condition, chemically induced male sterility and manual emasculation.

Advantages

- Hybrids exploit both GCA and SCA and utilize heterosis at greatest possible extent.
- Hybrids are more uniform than open pollinated varieties, synthetics and composites.
- Hybrids can be maintained in the form of their parental inbreds to avoid genetic contaminations or mutations.
- Hybrid yield is higher than pure lines.

Limitations

- Farmers have to purchase hybrid seed every season and cost is higher than varieties.
- Hybrid seed production is tedious process and requires technical skill.
- Production of hybrid requires more or sufficient inputs time to time.
- It requires to maintain isolation distances, which is not possible to fulfil every time.
- It is difficult to produce sufficient hybrid seed to cover larger areas of crop cultivation.

Synthetics: Utilization of synthetics first proposed by Hayes and Garber in 1922. Synthetic variety is developed by crossing no. of compatible lines in all possible combinations each other. Synthetics can be maintained in isolation through open pollination. The lines selected to produce synthetics are may be, inbreds, clones, open pollinated variety or other populations which tested for GCA.

Procedure: Top cross / poly cross test for GCA evaluation of lines is performed and superior lines are selected as parents.

Method-1: Equal amount from parental lines (*Syn_0*) are mixed and planted in isolation. Allow for open pollination in all possible combinations. The seed should be harvested in bulk. The population raised from this seed is the *Syn_1* generation.

Method-2: The parental lines are grown in isolated crossing block and allow for inter-crossing in all combinations. Equal quantity of seed from all crosses is composited to produce *Syn_1* generation.

The synthetics can be maintained by random mating from generation to generation i.e., *Syn_1* to *Syn_2* and *Syn_3* and so on. But the performance of *Syn_2* is lower than *Syn_1* due to loss in heterozygosity and formation of new gene combinations. The *Syn_3* and next generations performance id comparable to *Syn_2* according to Sewall Write equation in 1922. *Syn_2* generation is equal to breeder seed class.

The performance of *Syn_2* can be enhanced by increasing the no. of parental lines, increase the performance of parental lines/ single crosses.

Advantages

- Synthetics offers to exploit heterosis in crops where pollination control is difficult and hybrid development is not commercially possible.
- Farmers can produce the seed for next generation and no need to purchase seed in every season.
- Due to wide genetic base, synthetics do perform better than hybrids.
- Cost of synthetics is lower than hybrids.
- Synthetics are good reservoirs of the genetical variability.

Limitations

- Synthetics exploits only GCA but not SCA. Hence, the performance is lower than single cross hybrids, as hybrids use both GCA and SCA.
- Synthetics performance will be adversely affected by the parental lines having lower GCA.
- Synthetics can be developed only in cross pollinated crops, whereas hybrids can be produced both in self and cross-pollinated species.

Composites

Composite variety can be developed by mixing the seeds of many superior lines and encouraging open pollinate to produce crosses in all combinations among mixed lines. These are maintained through open pollination in isolation.

Achievements

In 1967 first composite varieties released in India are, Amber, Jawahar, Kisan, Vikram, Sona & Vijay in maize. These are followed by development of no. of composite varieties in maize crop till now, *viz*., CO1, NLD, Renuka, Kanchan, Diara 3Shakti, Ratan, Protina. Composite 1 in *Brassica compestris* var. *toria*.

Conclusion

The chapter explains the breeding methods for both self-pollinated and cross-pollinated crops, highlighting the distinct approaches required for each. For self-pollinated crops, methods such as pure-line selection, mass selection, and the pedigree method are used to achieve genetic uniformity and improve specific traits through controlled selection processes. In contrast, cross-pollinated crops benefit from methods like recurrent selection, hybridization, and the development of synthetic varieties, which focus on maintaining genetic diversity and exploiting heterosis. This chapter underscores the importance of these methods in addressing the unique breeding challenges posed by different crop types. By applying these tailored strategies, significant advancements in crop improvement have been achieved, contributing to enhanced yield, resilience, and adaptability in various agricultural contexts. As agriculture continues to face evolving challenges, the ongoing refinement and combination of these breeding techniques with modern breeding techniques along with other disciplines like molecular biology and biotechnology will be helpful in meeting the demands of a growing population while maintaining environmental sustainability.

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