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14. Distant Hybridization in Crop Improvement

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Abstract:

Crop improvement through interspecific and intergeneric hybridization has increased agricultural output and resilience. Disease resistance and yield improvement have been transferred to wheat, cotton, and tobacco by interspecific hybridization. Rust-resistant wheat and Yellow Vein Mosaic Virus-resistant Parbhani Kranti okra are notable achievements. Intergeneric hybridization, however rare due to its complexity, has produced important innovations like Triticale, a wheat-rye hybrid. Cross incompatibility, F1 hybrid sterility, and allopolyploidy issues persist despite these accomplishments. Hybridization *efficacy depends on polyploid resistance to genetic perturbations and gene transfer efficiency in closely related species.*

Ploidy manipulation, reciprocal crossing, and growth regulators have overcome several limitations, making hybridization more useful in crop improvement. Genetic engineering is changing the focus to more precise approaches like gene isolation and transformation, enabling more targeted and efficient crop development efforts. Plant breeding relies on hybridization to solve agricultural problems and boost global food security.

Keywords

Wide Hybridization, Sterility, Crop Yield, Introgression, Wide Cross, Hybrid.

14.1 Introduction:

Hybridization in crop improvement programmes usually uses different kinds of the same species as parent plants. This method typically guarantees a direct procedure for producing hybrids and following generations, except for special obstacles such as self-incompatibility, male sterility, hybrid necrosis, or chlorosis.

Nevertheless, there are situations in which it is advantageous or required to interbreed individuals from two distinct species, or even different genera.

Interspecific or distant hybridization refers to a sort of hybridization that leads to distant or wide crossovers. Intergeneric hybridization is the term used to describe the process of hybridization between organisms from different genera.

A Historical Overview:

- **1717**: Thomas Fairchild achieved the first recorded distant hybridization in crop improvement by crossing carnation (*Dianthus caryophyllus)* with sweet william (*Dianthus barbatus*).
- **Late 19th and early 20th centuries**: Numerous interspecific hybrids were created, primarily for academic purposes. However, some, especially among ornamental plants, became commercially significant.
- **Around 1890**: The first intergeneric hybrid, *Triticale*, was developed by Rimpau. Triticale is an amphidiploid resulting from the crossbreeding of wheat and rye.
- **1928**: Russian scientist Karpechenko produced an intergeneric hybrid, *Raphanobrassica,* by crossing radish (*R. sativus*) with cabbage (*B. oleracea* var *capitata*).
- **Mid-20th century**: Approximately 50 years of extensive research significantly improved the characteristics of triticale, making it suitable for cultivation in certain regions.
- **Present-day**: Distant hybridization plays a crucial role in crop improvement programs. While some crops like sugarcane (*S. officinarum*) rely primarily on interspecific hybridization, in most cases, distant hybridization is utilized for the transfer of specific desirable genes.

14.2 Types of Distant Hybridization:

Distant hybridization is of two types

- Interspecific hybridization
- Intergeneric hybridization

A. Interspecific Hybridization:

Interspecific hybridization is the term used to describe the crossing or mating between two different species within the same genus. Interspecific hybridization, which occurs between two species of the same genus, is often referred to as intrageneric hybridization.

B. Intergeneric Hybridization:

Intergeneric hybridization is the process of breeding between two different genera within the same family. These crosses are rarely utilized in crop enhancement due to a number of problems associated with them.

Understanding the Differences: Interspecific vs. Intergeneric Hybridization

Table 14.1: Interspecific vs. Intergeneric Hybridization

Criteria	Interspecific Hybridization	Intergeneric Hybridization
Definition	Crossing between two different species of the same genus.	Crossing between two different genera of the same family.
Desirable character source	Used when the desirable character is not found within the crop's species.	Used when the desirable genes are not found in different species of the same genus.
Gene transfer method	Effective for transferring genes from related cultivated or wild species into cultivated plants.	Utilized for the transfer of specific characters from allied genera into cultivated species.
Propagation success	More successful in vegetatively propagated species like sugarcane and potato.	Generally used in asexually propagated species.
Types of crosses produced	Can produce fully sterile, partially fertile, or fully fertile crosses.	F1 hybrids are typically sterile; fertility may be restored through chromosome doubling.
Introgression	Leads to introgression, which is the transfer of some genes into the genome of another species.	While challenging, introgression is achievable with advanced breeding techniques and is used to incorporate specific genes from one genus to another.

Criteria	Interspecific Hybridization	Intergeneric Hybridization
Use in crop improvement	Widely used and successful in crop improvement programs.	Rarely used in crop improvement due to various associated problems.
Development of new crop species	Not typically associated with the development of new species.	Has been used by some researchers to develop new crop species.
Seed setting	More than one seed setting is possible.	Seed setting is not possible.
Fertility	Hybrids can vary from completely sterile to fully fertile.	Hybrids are always sterile; sterility can be overcome by chromosome doubling.
Parents involved	Involves two species of the same genus.	Involves two genera of the same family.
Evolution of new crops	Possible but sometimes difficult.	Not possible with interspecific crosses; less possible than intergeneric crosses.
Example	*G. hirsutum x G. barbadense, T. aestivum x T. compactum, T. aestivum x T. durum, N. digluta x N. tabacum, G. max x G. soja etc.*	*Triticale*, a cross between wheat and rye, *Raphanobrassic*, a cross between radish and cabbage, Maize-Tripsacum crosses etc.

14.3 Examples of interspecific and intergeneric hybridization

A. Interspecific hybridization

Fully Fertile Crosses:

- **Cotton:**
  - ✓ *G. hirsutum* (2n = 52) x *G. barbadense* (2n= 52) = F1 fully fertile
  - ✓ *G. arborium* (2n= 26) x *G. herbaceum* (2n=26) = F1 fully fertile
- **Wheat:** *T. aestivum* (2n=42) x *T. compactum* (2n=42) = F1 fully fertile
- **Soybean:** *G. max* (2n=40) x *G. soja* (2n=40) = F1 fully fertile

Partially Fertile Crosses:

- **Wheat:** *T. aestivum* (2n=42) x *T. durum* (2n=28) = F1 Partially fertile
- **Cotton:** *G. hirsutum* (2n=52) x *G. thurberi* (2n =26) = F1 Partially fertile
- **Tobacco:** *N. digluta* (2n=72) x N. *tabacum* (2n=48) = F1 Partially fertile

Fully Sterile Crosses:

- *B. nigra* (2n=16) x *B. oleracea* (2n=18) **=** F1 sterile (2n=17) → Colchicine treatment = *B. carinata* (2n=34)

- *B. nigra* (2n=16) x *B. campestris* (2n=20) = F1 sterile (2n=18) → Colchicine treatment = *B. juncea* (2n=36)
- *B. oleracea* (2n=18) x *B. campestris* (2n=20) = F1 sterile (2n=19) → Colchicine treatment = *B. napus* (2n=38)

B. Intergeneric Hybridization:

- **Wheat-Rye cross (Rimpu, 1890):**
  - ✓ Wheat (*T. aestivum* 2n = 42) x Rye (*Secale cereale* 2n = 14) = F1 sterile (2n=28) → Colchicine treatment = *Triticale (*2n=56)
  - ✓ This process integrates the yield potential and grain quality attributes of wheat with the hardiness characteristic of rye
- **Radish cabbage cross (Karpechenko, 1928):**
  - ✓ Radish *(Raphanus sativus)* x Cabbage *(Brassica oleracea)* = F1 sterile→ Colchicine treatment = *Raphanobrassica*
  - ✓ The hybridization of radish and cabbage aimed to amalgamate the root traits of the radish with the leaf characteristics of the cabbage. However, the resultant species exhibited an inversion of the intended traits, featuring cabbage-like roots and radish-like leaves, rendering the combination impractical for agricultural purposes.

14.4 Key Challenges in The Production of Distant Hybrids:

In the field of plant breeding, creating distant hybrids is a complex task that calls for exact genetic balance and compatibility.

We shall thoroughly examine the various biological obstacles that arise during the process of combining genetic elements from different species.

- **Failure of zygote formation**: This occurs when fertilization is unsuccessful, often due to the pollen tube's inability to reach or properly grow within the embryo sac. This failure can be due to structural mismatches, such as a too-long style or differences in pollen tube thickness between species.
- **Failure of zygote development**: After successful fertilization, the zygote may still fail to develop due to various reasons: lethal genes that kill the embryo, genotypic disharmony causing genetic imbalances, chromosome elimination where one parent's chromosomes are lost, incompatible cytoplasm leading to hybrid weakness, and endosperm abortion, where poor endosperm development hinders embryo growth.
- **Challenges in hybrid seedling growth**: Even if a zygote develops successfully, the resulting seedling may face challenges. These include chlorophyll deficiencies, resulting in weak or non-viable plants, and other developmental anomalies. This stage can be affected by complementary lethal genes, causing issues like chlorosis or necrosis in the hybrid seedlings.
- **Genetic mechanisms of hybrid incompatibility:** These barriers contribute to reproductive isolation and species differentiation. They are often the result of gene duplication and divergence during speciation, leading to incompatible interactions in hybrids. These incompatibilities can manifest in various ways, from sterility to lethal effects, and are often complex, involving multiple genes and pathways.

14.5 Techniques to Make Wide Crosses Successful:

In the realm of plant breeding, the process of producing hybrids between species that are genetically distant, referred to as wide crossings, requires the use of specific procedures to overcome natural obstacles. The methods encompass a variety of techniques, starting from initial crossing strategies and extending to advanced post-fertilization interventions.

Each of these techniques plays a crucial part in ensuring the effective development of these hybrids.

- **Optimal parent selection**: Choosing genetically compatible parents within a species to enhance cross-compatibility in wide crosses.
- **Reciprocal crossing**: Implementing reciprocal crosses, beneficial in cases like the interspecific cross between *Vigna radiata* and *V. mungo*.
- **Ploidy manipulation**: Adjusting chromosome numbers through doubling to match ploidy levels of different species, aiding in zygote formation.
- **Pollen mixture usage**: Utilizing a mix of compatible and incompatible pollen to overcome cross incompatibility and facilitate pollen tube growth.
- **pistil manipulation**: In cases like maize-Tripsacum crosses, adjusting pistil length can enable the shorter pollen tube to reach the ovule.
- **Growth regulators application**: Using growth regulators such as IAA, NAA, 2,4-D, and gibberellic acid to accelerate pollen tube growth or extend pistil viability.
- **Increasing cross volume**: Performing a large number of crosses to improve the odds of obtaining viable seeds, given the generally low success rate in wide crosses.
- **Bridge crossing**: Employing a third species as a bridge in cases where two target species cannot cross directly, as in the indirect crossing of *Nicotiana repanda* with *N. tabacum* via *N. sylvestris*.
- **Embryo culture**: Widely used in species like *Triticum*, *Hordeum*, and *Nicotiana*, this technique helps develop viable hybrids when natural zygote development is hindered.
- **Grafting for hybrid survival**: Enhancing the survival and flowering of interspecific hybrids, as demonstrated in sugar beet (*Beta vulgaris*) and certain *Trifolium* and *Glycine* hybrids.
- **Protoplast fusion**: An alternative approach for creating wide crosses, especially when traditional sexual fusion is not feasible, though this method still requires further refinement for practical breeding applications.

14.6 Enhancing Crop Improvement through Distant Hybridization:

Distant hybridization has been instrumental in advancing crop improvement, leveraging the genetic diversity found across different species. This approach not only enriches the genetic pool but also introduces beneficial traits into cultivated crops. Below are key applications of this technique in crop improvement, each underscored with an example:

- **Creation of new crop species:** By crossing species and inducing chromosome doubling in sterile hybrids, new allopolyploid crop species are developed. A prime example is Triticale, a successful synthetic crop derived from wheat and rye.

- **Development of alien addition and substitution lines:** This involves incorporating chromosomes or chromosome segments from one species into another. In wheat, alien addition lines have introduced disease resistance traits from wild relatives.
- **Transfer of small chromosome segments for specific traits**: This method is crucial for introducing specific desirable genes, like disease resistance, from one species to another. An example is the transfer of black arm resistance from *Gossypium barbadense* to *Gossypium hirsutum*.
- **Utilization as new varieties:** Some distant hybrids are directly used as new crop varieties due to their advantageous traits. The hybrid cotton variety 'Varalakshmi' is an example, offering high yield and quality.
- **Transfer of cytoplasm:** This technique involves transferring the cytoplasm of one species to another to produce desirable traits, such as cytoplasmic male sterility.
- **Development of disease resistance:** Many crops have benefitted from genes for disease resistance transferred from wild relatives, as seen in wheat with rust resistance genes from related species.
- **Improving adaptation and quality:** Distant hybridization has contributed to broader adaptability and improved quality in crops. For instance, cold tolerance in wheat and increased protein content in rice are outcomes of this approach.
- **Yield improvement:** Wild relatives of crops like oat and chickpea have been used to increase yield significantly through distant hybridization.
- **Enhancing other characteristics:** This method has also improved various other traits in crops, such as plant stature in wheat and oil quality in oil palm.

14.7 Enhancements via Interspecific Hybridization in Crop Breeding:

The table below highlights key examples of how plant breeders have improved common crops. By crossing species, transferred traits like disease and pest resistance into different crop.

Table 14.2: Enhancements via Interspecific Hybridization in Crop Breeding

Crop	Transferred Trait	Donor Species	Recipient Species	
Okra	Resistance to Yellow Mosaic Virus	*Abelmoschus manihot*	*A. esculentus*	
Peanut	Resistance to Leaf Chewing Insects	*Arachis monticola*	*A. hypogaea*	
Potato	Resistance to Late Blight, Leaf Roll and Virus X	*Solanum demissum*	*S. tuberosum*	
Strawberry	Red Stele and Aphid Resistance	*Fragaria chiloensis*	*Cultivated strawberry*	
Sugarcane	Sereh Disease Resistance	*Saccharum spontaneum*	*S. officinarum*	
Tobacco	Resistance to Mosaic Virus	*Nicotiana glutinosa*	*N. tabacum*	

Crop	**Transferred Trait**	**Donor Species**	**Recipient Species**	
Tobacco	Resistance to Wild Fire and Blackfire Diseases	*N. repanda*	*N. tabacum*	
Tobacco	Resistance to Blue Mould, Black Root Rot, Wild Fire and Fusarium Wilt	*N. longiflora*	*N. tabacum*	
Wheat	Resistance to Eyespot	*Aegilops ventricosa*	*Triticum aestivum*	
Wheat	Rust Resistance	*Agropyron*	*Triticum aestivum*	
Cotton	Jassid Resistance	*Gossypium tomentosum*	*G. hirsutum*	
Cotton	Smoothness for boll, Weevil Resistance	*G. armourianum*	*G. hirsutum*	
Cotton	Rust Resistance	*G. raimondii*	*G. hirsutum*	
Cotton	Blackarm Resistance	*G. arboreum*	*G. barbadense*	

14.8 Limitations of Distant Hybridization in Crop Improvement:

Distant hybridization, while a valuable tool in the field of crop breeding, is subject to several significant limitations that can hinder its effectiveness and applicability. These challenges range from biological incompatibilities to practical issues in breeding, underscoring the complexity and resource-intensive nature of this technique.

Understanding these limitations is crucial for optimizing the benefits of distant hybridization in developing improved crop varieties.

- **Incompatible crosses**: Many distant crosses, despite various techniques, remain unachievable. This often leads to a trial-and-error approach, especially in intergeneric and interfamily crosses, where the reasons for failure are not always clear.
- **F1 hybrid sterility**: F1 hybrids from distant crosses frequently exhibit sterility, ranging from partial to complete. Overcoming this requires specialized techniques, such as chromosome doubling, which may not always be feasible.
- **Difficulties in new species creation**: The development of new crop species through allopolyploidy is often challenged by issues like reduced yield, poor agronomic traits, and sterility, necessitating extensive breeding efforts.
- **Reduced homoeology**: The lack of chromosome pairing between parental species limits the transfer of oligogenes, requiring complex chromosome manipulations, mainly viable in polyploid species.
- **Linkage drags**: Often, desirable genes are linked with undesirable ones, complicating their use in crop improvement. Although continued breeding can sometimes resolve this, it demands significant time and resources.

- **Transfer of recessive and quantitative traits**: Transferring recessive traits and quantitative characters through distant hybridization is often impractical, with dominant monogenic traits being the most successfully transferred.
- **Flowering issues in F_1 hybrids**: Some F1 hybrids, like those in the genus Glycine, may not flower at all, posing a significant barrier to further breeding.
- **Crossing challenges with improved varieties**: Often, the best varieties of a crop species are not easily crossable with wild species, necessitating the use of older, less improved varieties for distant hybridization.
- **Seed Dormancy**: In some interspecific hybrids, such as in Arachis, F1 seeds exhibit prolonged dormancy, complicating their use in crop improvement programs.

14.9 Factors Influencing the Success of Distant Hybridization in Crop Breeding:

The effectiveness of distant hybridization in crop improvement is influenced by several factors, each playing a crucial role in determining the likelihood of successful gene transfer. These factors are outlined below in a structured and professional manner:

- **Higher tolerance in polyploids**: Polyploid species, due to their multiple sets of chromosomes, exhibit greater genetic buffering capacity. This ability to tolerate genetic disturbances makes them more amenable to accepting genes from other species compared to diploids.
- **Advantage in cross-pollinated species**: Species that are predominantly cross-pollinated tend to benefit more from interspecific gene transfers. Their inherent high heterozygosity allows for greater genetic variability, facilitating the integration and expression of foreign genes.
- **Gene transfer efficiency in closely related species**: The likelihood of successful gene transfer is higher in closely related species. This is primarily due to the greater homology in their chromosome structures, which enhances the compatibility for gene integration.

14.10 Successes in Crop Improvement Through Distant Hybridization:

Distant hybridization has been instrumental in enhancing crop varieties, particularly in the transfer of specific traits like disease resistance. A notable example is the introduction of rust resistance genes into wheat from its wild relatives.

In the case of bhindi (Abelmoschus esculentus), the *Parbhani Kranti* variety, developed from a cross with *A. manihot,* exhibits complete resistance to Yellow Vein Mosaic Virus (YVMV) and shows improved yield in both kharif and summer seasons compared to the *Pusa Sawani* variety. Additionally, this technique has been effective in producing cytoplasmic male sterile lines in crops like wheat, tobacco, and cotton. While its application in creating new crop varieties is somewhat limited, its success in sugarcane improvement is noteworthy. Furthermore, the combination of distant hybridization and chromosome doubling presents a promising avenue for developing new crop species, as demonstrated by the creation of *Triticale.*

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