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Wide Hybridization: A Technique to Bring Far Relatives of Vegetables in Use

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Wide hybridization is the technique of combining the wild types with the cultivated forms. Breeding for wide hybridization helps to extend the gene pool of crops when the cultivated species are deprived of the required variations for achieving the goal of the breeder. In vegetables though there is huge variability present but most of the existing varieties are vannaourable to modern hurdles of crop production. Through this approach of gene transfer trait of interest such as pest resistant, disease resistance, drought tolerance, salinity tolerance increament in yield, earliness, quality improvement, increased number of fruits, modification in the sex ratio etc. can be transferred to the existing varieties. There are many hurdles in getting the desirable crosses in both inter specific and inter generic hybridization but it can be overcome by many techniques such as embryo rescue technique, Ovary culture, Ovule culture, backcrossing etc. Thus, distant hybridisation gives ample scope for bringing the trait of interest present in the secondary and tertiary gene pool into the core collection and effectively utilizing it in the present vegetable breeding.

To enhance ecological sustainability and mitigate biotic and abiotic stress in cultivated vegetable crops, wide hybridization has been championed as a potent tool for plant breeders. Wild species serve as reservoirs of valuable traits, superior quality, processing attributes and resistance to environmental stresses. Crop wild relatives has long been utilized in breeding to transfer genes for pest, disease, and abiotic stress resistance to cultivated species. Wide hybridization combines conventional breeding and modern molecular techniques, offering an efficient approach for crop improvement.

Wide hybridization involves interbreeding species or genera to introduce economically valuable genes into cultivated species. It includes interspecific hybridization within the same genus and intergeneric hybridization within the same family. This method effectively transfers desirable traits from related species and genera to cultivated plants, with greater success observed between closely related species or genera.

The first distant hybridization occurred in 1717 when Thomas Fairchild crossed carnation and sweet william, resulting in Fairchild's mule. Vegetables are essential for providing vital nutrients, particularly in developing and underdeveloped countries. Allied species, including wild varieties, are crucial in breeding programs for their disease resistance, pest tolerance and quality attributes. Traits such as enhanced carotenoid and starch content have been improved through the use of wild relatives. Additionally, wild species contribute to environmental adaptation, such as cold tolerance, moisture stress tolerance, high temperature effects, salinity tolerance etc. in various crops. Overall, wild species play a significant role in vegetable breeding, offering diverse and beneficial characteristics.

Hurdles Associated with Successful Wide Hybridization in Vegetables

Spatial Isolation: Geographical distance, temporal and environmental barriers, as well as sensitivity to photoperiod and specific latitudes, can deviate the reproductive cycle of the vegetables thus isolating both the required species from each other. The development of distinct maturity groups in crops like knol khol, radish, and cauliflower is a consequence of spatial isolation.

Pre-Fertilization Barriers: These barriers operate between the parental species, preventing crossability by hindering the fertilization process. This disruption of fertilization in interspecific crosses is also known as interspecific incompatibility or incongruity. Lack of pollen-stigma recognition primarily contributes to incongruity. This response is sporophytic and is associated with pollen wall materials.

1. **Failure Of Pollen Germination:** Conventional breeding attempts to produce interspecific hybrids in Cucumis species were unsuccessful due to a pre-fertilization barrier. This barrier was identified by the failure of pollen germination even after 72 hours post-pollination. Kaneko and Bang (2014) reported a similar issue in Brassica campestris and Raphanus sativus.
2. **Swollen Pollen Tube Growth:** This phenomenon is frequently observed in failed wide crosses. Incompatibility in Cucumis spp. manifests as delayed pollen growth, halted pollen tube growth in the stigma, or failure of pollen tubes to reach the ovules (Chen and Adelberg, 2000). Categorization of African Cucumis crosses into three groups—bilateral congruity, bilateral incongruity, and unilateral incongruity is based on pollen tube growth behavior.
3. **Lack of fertilization:** In these instances, the pollen tube successfully delivered the two sperm nuclei to the embryo sac. In one scenario, a zygote was formed but endosperm development did not occur, while in another case, 10 percent of crosses resulted in endosperm development but without embryo formation.

Post fertilization barriers: These barriers are active in distant hybrids and their offspring, commonly referred to as post-zygotic barriers. They encompass embryonic breakdown, zygote development failure, abnormal fertilization, and inhibition of endosperm and embryo development.

1. **Hybrid Embryo Abortion:** Embryo development arrest or abortion has been observed in numerous interspecific hybrids. The primary barrier to interspecific hybridization in Phaseolus species, such as Phaseolus vulgaris × P. acutifolius, is embryo abortion. In the case of Phaseolus coccineus × P. vulgaris, abnormal embryo development is noted.
2. **Hybrid inviability:** Hybrid lethality in F_1 seedlings stems from genetic discordance during zygote development, leading to high mortality, stunted growth, chlorosis, and premature death in hybrid plants. This disharmony may arise between species' nuclei and cytoplasm or within the nuclei themselves. Specific genes, like those found in crosses such as Cucumis sativus × C. melo and Abelmoschus esculentus × A. tetraphyllus, trigger lethality, chlorosis, and weakness in F_1 hybrids.
3. **Hybrid Sterility:** Hybrids exhibit a lack of seed set due to hybrid sterility, stemming from lethal gene expression, genetic imbalance caused by chromosomal non-homology, chromosomal elimination, and endosperm abortion. Numerous interspecific hybrids, such as those of Abelmoschus esculentus × A. ficulneus and Abelmoschus esculentus × A. tuberculatus, display notably low seed set rates.
4. **Failure of Flowering in The Progenies:** Hybrids often display either absent or severely deformed and non-functional reproductive structures. This occurs due to a failure in physiological differentiation, resulting in dysfunctional reproductive systems caused by meiotic failure in one or both sexes.
5. **Hybrid breakdown:** In some wide crosses, while initial generations may show normal seed setting and fertility, later generations like F_2 often exhibit reduced performance, sometimes leading to complete sterility. Afful et al. (2018) found fruit set failure in crossability studies of cultivated brinjal with wild accessions such as Solanum torvum, S. anguvi, and S. aethiopicum, especially when wild accessions were used as female parents.

Examples of Successful Interspecific Crosses in Vegetables Through Different Techniques

Ploidy Level Manipulation: Careful selection of parents is crucial for successful wide crosses, often resorting to reciprocal crosses if initial attempts fail. Due to low seed set rates, pollination of a large number of flowers is necessary. Ploidy levels manipulation has been used in crosses like B. oleracea × B. campestris to produce fertile hybrids. Distant hybrids often suffer from high sterility due to genetic differences. This issue is commonly resolved by doubling the chromosome number of the F_1 hybrid. Bharathi et al. (2014) crossed natural tetraploid Momordica subangulata subsp. renigera with induced tetraploid Momordica dioica, creating a new species named Momordica x suboica Bharathi. This hybrid retains its morphological characteristics and superior agronomic traits, presenting a promising option as a new vegetable crop.

Use of Bridging Species: Traits such as bush habit and disease resistance have been transferred between Cucurbita species using bridging species like C. lundelliana. Capsicum chinense has also served as a bridge between other Capsicum species.

Use of Growth Regulators: Growth Regultors (GRs) enhance the zygotic formation in distant hybrids of many cucurbits, okra and tomato. Commonly used GRs are IAA, IBA, GA3. GA3 75ppm application to maternal plant 1 or 2 days before and after pollination improved zygote formation, faster pollen tube growth, more embryo survival and more seed set in wide crosses. Application of auxin in Solanum prevented flower abscission and enhanced fruit set. Growth regulators like IAA and NAA show promise in enhancing pollen tube growth, while interspecific somatic hybrids between eggplant and Solanum torvum exhibit resistance to Verticillium wilt in brinjal.

Embryo Rescue Technique: Embryo abortion is the major barrier in distant hybridization. It can occur at any stage of development depending on the genomic relationship of two parental species.Embryo rescue technique was used in Solanum lycopersicum × S. sitiens hybrids to induce drought, salinity and low temperature resistance in tomatoes (Chetelat, 2016). Capsicum chinense, C. annuum and C. frutescens were crossed with each other and embryo rescue was done between 27-33 days after pollination by Debbarama et al., 2013. Ovary culture, Ovule culture, backcrossing also can be done.

Ovule Culture: Wide crosses showing poor fertility can be back crossed to cultivated species to improve the fertility of hybrids. Backcrossing can be applied to balance cytoplasmic interaction by producing cybrids or alloplasmic lines.

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Chamola et al. (2015) utilized cytoplasmic male sterile (CMS) lines from Brassica juncea and B. napus to transfer CMS to cauliflower (B. oleracea). Embryo rescue was employed in BC_1 and BC_2 generations. Recovery of the recurrent parent phenotype was faster in B. napus x B. oleracea than in B. juncea x B. oleracea. BC_3 generation plants of B. napus x B. oleracea exhibited good curd formation and complete male sterility, while those of B. juncea x B. oleracea were male sterile but retained genetic elements of B. juncea.

Distant hybrids often suffer from high sterility due to genetic differences. This issue is commonly resolved by doubling the chromosome number of the F_1 hybrid. Bharathi et al. (2014) crossed natural tetraploid Momordica subangulata subsp. renigera with induced tetraploid Momordica dioica, creating a new species named Momordica x suboica Bharathi. This hybrid retains its morphological characteristics and superior agronomic traits, presenting a promising option as a new vegetable crop.

Conclusion

In conclusion, wild species serve as valuable repositories of novel genes, making them indispensable for wide hybridization programs. Despite the numerous barriers associated with wide hybridization, it remains a crucial tool for genetic enhancement in vegetable crops. While technically challenging and knowledge-intensive, these barriers can be overcome through both conventional and biotechnological approaches. To expand the genetic diversity, wide hybridization combined with in vitro and biotechnological methods is increasingly utilized. This approach is particularly vital for breeding disease and insect-resistant varieties and enhancing the quality of cultivars, addressing the current needs of agriculture.

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