

Review Article

Wild genetic resource in vegetable improvement: applications and strategies

ABSTRACT

Domestication of feral types of the present day cultivated types was in vogue in earlier days of farming followed by the selection and hybridization that led to many improved varieties. Expression of traits faded in these due to development of homozygosity as a consequence of continuous interventions like selection and selfing in same set. Relying on wild relatives that are found to be the source of many target genes found significant. While, the usage of wild relative is not so easy, because of the barriers that reside in distant hybridization, consequences like failure in zygote and embryo formation, embryo death, linkage drags, incompatibility within wild and cultivated groups etc are the major. Strategies like bridge crosses, somatic hybridization, grafting, embryo rescue etc., techniques are found to combat these issues. Vegetables are the group of crops which mainly cultivated for their high returns and quality aspects for healthy food routine of the consumer. This review will spotlight the recent advances in vegetable improvement through their wild relatives and available strategies to overcome the barriers in the usage of wild relatives in vegetable improvement.

Keywords: Bridge cross, Embryo rescue, Polyploidy, Somatic hybridization, Vegetable grafting.

1. INTRODUCTION

As it is well established vegetables perform their prominent role in combating the insufficiency of the global food demand in terms of nutrition. Hence, the vegetables are eulogized to be protective food. The varietal wealth of the vegetables are found to be unique in terms of their nutrition profiles. The present varieties and hybrids of vegetables not only nutritionally rich they also possess some of the important traits that are being resistant to some of the potential biotic (pest and diseases) and abiotic (climate and soil) factors hindering the production of vegetable produce to fulfil the demand of consuming community[1].

Although, the development of an ideal variety of a crop in all sense, seems to be fictional, it is of utmost importance to be accomplished to fulfil consumer demand. The present day cultivars at once when they were considered to be novel were found to be having all these desired characters, for instance the okra variety Pusa Sawani when released was found to be the one high yielding variety due its resistance towards Yellow Vein Mosaic Virus (YVMV) but with the time, resistance of the variety found to be faded, the reasons may be the build-up of new viral strains against resistance mechanism, hindered genetic diversity in the existing germplasm due to selection pressure or any other demanding the search for new source of resistance[1]. The most reliable treasure of these genes of interest lies in the feral types these are the crops far related to the cultivated crops which were somewhere left behind in the wild in the course of domestication in the earlier days with some issue with transfer of genes to their cultivated relatives. The common introgression difficulties that are pre-syngamic (incompatibility, pollen tube death, etc.) and post-syngamic (embryo abortion, hybrid sterility, linkage drag, etc.). Many of the strategies have been designed to overcome the difficulties and surpass the challenges in utilization of the wild relative as a source of target alleles/ genes in improvement of an ideal vegetable variety.

In this manuscript the available wild source for useful traits (**Table 1**) and potential of the wild relatives in the crop improvement and the possible challenges to overcome with the potent strategies are been reviewed with special interest to vegetable crops. This could spotlight the possibilities of utility of wild types in crop improvement.

2. CROP WILD RELATIVES IN VEGETABLE IMPROVEMENT

In the domestication and the subsequent selection pressure (human and natural) towards their sustenance and suitability resulted in the attainment of homogeneity resulting loss in diversity among cultivated forms, thereby the difference being non-significant in one or the other kind that hampered variability in germplasm, this may be referred as 'domestication bottleneck'[2]. This negative effect of domestication that led loss of germplasm diversity can be surpassed by the use of crop wild relatives that are sources of many useful traits in varietal development would bring the enhanced effect in terms of commercial yield, resistance biotic hindrances, increment in the quality traits and also the wild gene introgression may also result in the improved adaptability to non-congenial abiotic factors.

In vegetable improvement there are many instances where these wild relatives are involved in crop improvement in all the mentioned aspects, the notable citations in the important vegetable crops are

mentioned below with some noteworthy information that would support the use of wild relatives in vegetable improvement.

Table 1: Wild relatives as a source of targeted traits in vegetable improvement

Vegetable crop	Wild relative	Targeted trait	Reference
Tomato (<i>Lycopersicon esculentum</i>)	<i>L. hirsutum</i> and <i>L. peruvianum</i>	Fungal resistance	[3]
	<i>L. peruvianum</i>	Nematode resistance Source for <i>Tsw⁵</i> gene (Spotted wilt resistance)	[3]
	<i>Solanum habrochaites</i>	Leaf eating caterpillar resistance Late blight resistance Source of Ty-2 gene (TYLCV)	[4,5]
	<i>S. pinnellii</i>	Fruit ripening, high brix content and tolerant to drought	[6]
	<i>S. pimpinellifolium</i>	High soluble solids	[7]
	<i>S. chesmanii</i> and <i>S. galapogense</i>	Salinity stress	[8]
	<i>S. Cheesmaniae</i>	Jointless gene (<i>j-2</i>), β carotene and thick skin	[9]
	<i>S. chemielewskii</i>	High sugar	[10]
	<i>S. neorickii</i>	Bacterial wilt resistance	[11]
	<i>S. chilense</i>	Resistance to drought and virus	[8]
	Brinjal (<i>Solanum melangena</i>)	<i>S. khasianum</i> and <i>S. aviculare</i>	Solasodine rich
<i>S. khasianum</i> and <i>S. viarum</i>		Resistance to shoot and fruit borer	[12]
<i>S. xanthocarpanum</i> and <i>S. torvum</i>		Resistance to phomopsis blight	[13]
<i>S. sisymbriifolium</i> and <i>S. auriculatum</i>		Resistance to little leaf	[14]
<i>S. macrocarbonum</i> and <i>S. gilo</i>		Tolerant to drought	[12]
<i>S. sisymbriifolium</i> and <i>S. indicum</i>		Resistance to root knot nematode	[14]
<i>S. integrifolium</i>		Fusarium wilt resistance	[12]
Chilli (<i>Capsicum annuum</i>)	<i>C. frutescens</i>	Small highly pungent perennial nature	[15]
	<i>C. pubescens</i> and <i>C. microcrpum</i>	Powdery mildew resistance	[16]
Potato (<i>Solanum tuberosum</i>)	<i>S. demissum</i>	Resistance to late blight, leaf roll and potato virus X	[17]
	<i>S. chacoense</i>	Charcoal rot resistance	[18]
	<i>S. verrucosum</i> and <i>S. microdontum</i>	Resistance for late blight	[19]
	<i>S. raphanifolium</i>	Tolerant to cold	[20]

		induced sweetening	
	<i>S. avilesii</i> , <i>S. terijense</i> , <i>S. chacoense</i> and <i>S. veturii</i> .	Source for <i>Rpigene</i> (resistance to late blight)	[21]
Okra (<i>Abelmoshufesculentus</i>)	<i>A. tuberculatus</i>	Symptomless resistance to YVMV	[22]
	<i>A. manihot</i> var. <i>manihot</i>	Immune to YVMV	[23]
	<i>A. pungens</i>	True resistance to YVMV	[23]
	<i>A. tuberculatus</i> and <i>A. caillei</i>	Tolerant to shoot and fruit borer	[22]
Cole crops (<i>Brassicasp.</i>)	<i>B. carinata</i>	Source of male sterility and powdery mildew resistance	[24]
	<i>B. nigra</i>	Chromosome B4 (resistance to <i>Leptosphaeria maculans</i> [blackleg])	[25]
	<i>B. hirta</i>	Resistance to leaf blight of cabbage	[26]
	<i>B. fruticulosa</i>	Male sterility to <i>B. juncea</i> , <i>B. oleracea</i> and <i>B. napus</i> .	[27]
	<i>B. napus</i>	Low euricic and low glucosinolate content	[28]
Sugar beet (<i>Betavulgris</i>)	<i>B. procumbens</i> , <i>B. webbiana</i> and <i>B. pettellaris</i>	Cyst nematode resistance	[29]
	<i>B. vulgaris</i> L. ssp. <i>maritime</i>	Cyst nematode resistance	[30]
Carrot (<i>Daucus carota</i>)	<i>D. carota</i> subsp. <i>carota</i> , <i>D. carota</i> subsp. <i>Capillifolius</i> and <i>D. carota</i> subsp. <i>Gummifer</i>	Abiotic stress (salt, drought and flood) tolerant	[31]
Cowpea (<i>Vignaungiculata</i>)	<i>V. luteola</i> , <i>V. marina</i> and <i>V. vexillat</i>	Salinity tolerance	[32]
	<i>V. radiate</i> var. <i>sublobata</i>	Yellow mosaic virus	[33]
	<i>V. unguiculata</i> groups <i>sesquipedalis</i>	Temperature and salinity stress tolerance	[34]
Pea (<i>Pisumsativum</i>)	<i>Lathyrus</i> spp.	Broomrape weed resistance	[35]

2.1 Yield Traits

In any crop improvement cycles the breeders certainly concentrate on the improvement of yielding capacity of the resulting varieties. Many conventional breeding strategies like heterosis breeding between two high yielding varieties or hybrids, correlational studies to indirectly bring in the increment in one such complex trait i.e., yielding capacity by concentrating on corresponding traits etc., are found to give satisfactory results in many vegetable crop. In this course the use of wild relative in interspecific hybridization programmes also shown the considerable high yielding potential in many vegetable asopined by Sun et al. [2] in the interspecific hybridization between *S. melangena* with the wild species *S. incanum* and *S. insanum* which are of primary gene pool resulted in the better fruit set along with good seed count in the fruit however, the fruits obtained by the cross with *S.*

sisymbriifolium were found to be parthenocarpic in nature which of processing significance. The increment in the yield can also be indirectly resulted by decreasing the unmarketable fruits in brinjal crop as reported by Bhatt et al. [36] the distant hybridization of Pant Rituraj with *S. gilo* (wild brinjal). *Solanum viarum* crossed with *S. melangena* proved to increase the marketable yield with very negligible incidence of fruit and shoot borer in brinjal confirmed through the RAPD (random amplified polymorphic DNA) markers. Bhatt et al. [36] crossed *Capsicum chinense*, *C. annuum* and *C. frutescens* among each other and confirmed the increment in yield both morphologically and through RAPD markers in chilli. As well established that Cole crops have their ogura CMS through their wild forms and this may be used in the improvement of cultivated farms Singh et al. [37] were proved that the CMS lines of wild origin namely *Ogu402-6A*, *Ogu76-33A* and *Ogu76-4A* being helpful in expression of earliness in cultivated farm upon introgression. Tan et al. [38] reported that the wild originated gene *CsACS2* the encoder of a candidate gene (1-aminocyclopropane-1-carboxylic acid synthase) for monoecism (*m*) that is associated with fruit shape (elongated) and yielding attributes of cucumber. Yield increment through wild relatives not only possible by hybridization, as reported by Kumar et al. [13] the wild *Solanum torvum* and *Solanum khasianum* upon their use as rootstock in grafting with two improved varieties Pusa Shamala and Pusa Hybrid 6 of *solanum melangena* type exhibited superiority in yielding capacity. The grafts of brinjal cultivar *GJB-3* on *S. torvum* were profitable in yielding ability [36]. The grafting success varies with the various root stock species, the graft of *Cucumis sativus* on *C. ficifolia* (fig leaf gourd) found to be highly successful (70.23%) on the other hand the root stock of *Legenaria siceraria* (bottle gourd) resulted in least (63.91%) success [39]. Wild tomato species (*L. pimpinellifolium*) found to give highest number of seed per plant, less days to flowering and fruit setting [40].

2.2 Quality Enhancement

Though getting high yield being one of the main objective of all the breeding proposals, along with the higher quantity of produce it is noticed that the produce that containing the best quality too will fetch a good price in market alongside the quality product also plays an important role in consumer health. Hence, there are many conventional breeding approaches to improve the quality traits of vegetable. However all the efforts for quality elevation of the vegetable are somewhere facing shortfall in the fulfilment of the objective. This may be due to the fact that is obvious less genetic diversity for nutritional traits in cultivated form where the usage of wild farms pronounces its importance. The CMS lines *Ogu13-85-6A*, *Ogu309-2A* and *Ogu2A* of wild origin can act as a parent for improving the head compactness in cabbage [37]. Among 18 introgression lines of somatic hybridisation between 'Korso' a wild type and *Brassica nigra*, introgression line 9 (*IL9*) was noticed to be with Potassium content: 236 mg/100 g [41]. With the use of wild relative the quality of the cucumber can be efficiently improved [42] as the wild progenitor species *Cucumis hardwickii* incorporated the small size to the fruits to ease the whole fruit canning and also the fruit vitamin A content can be improved by the β carotene promoter gene by crossing with *C. xishuangbannensis*. *Solanum galapogense* a wild relative to tomato found be the source for β carotene [13]. *Solanum melameanum* a wild species is reported to contain starch content of 15.45 to 23%. The genome study of two wild relatives (*Ipomoea trifida* and *I. triloba*) of sweet potato confirmed their use in crop improvement with regards to increased carotenoid

biosynthesis in the roots [43]. GABA (*γ-aminobutyric acid*) tomatoes are gaining the importance towards human health wild tomatoes are found to be very efficient source of gene encoding to GABA [44]. Ghani et al. [40] noticed that *Solanum pimpinellifolium* could be used successfully for improving the quality traits like total soluble sugars (TSS) and lycopene content in fruits. As flavour of tomato or any fruit is the critical factor for its consideration by consumer, flavour can be altered by variation in synthesis of sugar and amino acids, the wild tomato *S. pimpinellifolium* on QTL analysis found to have genes helpful in flavour enhancement of tomato and also this wild type of tomato found to be the accelerating factor of lycopene synthesis [37].

2.3 Biotic Stress Resistance

Biotic stress factors like insect pest and diseases are being one of the prominent constraints in food production that can be direct cause of detrimental quality and decreased quantity of the production. Majority of vegetable crops being very succulent in nature and also rich in nutrients that makes the vulnerable for the feeding of insect pest and infestation of serious pathogens respectively. Though there are many improved varieties in vegetable that bred through the conventional breeding methods and majority of the resistance varieties have also already lost the resistance for these biotic stress. This may be due the reason that the pest (pathogen and insect) will adopt for the resistance reaction and adopt to feed or survive on the resistance cultivar itself and eventually making the cultivar susceptible. One classical instance being the Pusa Sawani of okra that is the resultant of hybridization between IC-1542 × Pusa Makhmali which was notified to be resistant for the infestation by aphids and consequently resistant to the YVMV infestation, but for now this variety have lost its resistance towards the virus. Another case that is H24 (Hisar Anmol) of tomato which was evolved by the interspecific crossing of *Sel7* (Hisar Arun) with the *Lycopersicon hirsutum* f. *glabratum* adopting modified pedigree back cross method reported to be resistant for TLCV but this resistance have been degraded and brought it to the class of moderately resistant and it is not surprising if after some years or growing seasons it attains the rank of susceptible. This degrading resistance reaction in the developed varieties may be due numerous causes as evolution of virulence strains or insect life cycle, degradation in the purity of gene that is responsible for resistance or lack of maintenance breeding etc. resulting loss in resistance, this finally demands the rediscovery of resistance genes in the wild farms and incorporate such genes in the cultivated types. As reviewed by Karim et al. [45] the chilli wild relative *Capsicum chinense* PBC932 was able to donate the resistance to the cultivated *C. annuum*. The leaf cur of chilli caused by begomovirus through white fly vector and the wild species *S. pseudocapsicum* found to be asymptomatic to begomovirus [46]. *S. incanum* as wild relative of brinjal is found to decrease the incidence of *Leucinodes orbonalis* (fruit and shoot borer) by 5.3-8.6% over the years [47]. The wide hybridizations between cultivated *Brassic napus* and wild *B. rapa* subsp. *sylvestris* lines were also found efficient in transmitting the resistance along with linkage of a pair of SSR (simple sequence repeats) and IP (intron polymorphic) markers to club rot resistance in Cole crops by mapping the resistance gene on chromosome A03. IL6 found to be Resistant to clubroot race 4 among 18 introgression lines of somatic hybridization between 'Korso' a wild type and *Brassic nigra* [41]. In okra the biotic stress like white fly being the very destructive pest due to its virus (Yellow Vein Mosaic) transmitting nature, the wild species *Abelmoschus esculentus* proven to be 66%

efficient in being source for white fly resistance [48] along with this species the other wild species namely *A. manihot* and *A. moschatum* are also efficient in conferring the resistance against fruit borer and hoppers. The wild resource can be undoubtedly referred as treasure of resistance genes, the wild types of potato *Solanum albuca*, *S. andeanum*, *S. lesteri*, *S. longiconicum*, *S. morelliforme*, *S. stenophyllum*, *S. mochiquense*, *S. cajamarquense*, and *S. huancabambense* are reported to be resistance source for late blight disease of potato [49] in addition to *S. cajamarquense* one more wild from *S. sogarandinum* also found promising in late blight resistance breeding of potato [50]. In carrot improvement *Daucus scapillifolius* is trusted to be the source for carrot fly resistance.

2.4 Climate Resilience and Adaptation.

For successful cultivation of any crop the suitable or optimum climate is the prerequisite. It is noticed that the highly improved cultivation technology consisting of integrated nutrient management, well protected structure, high yielding varietal seed inputs though applied the failure of the suitable climatic condition (areal or soil) leads to the partial or complete failure of the crop. The vegetable crops are specially found to be very sensitive for unfavourable growing conditions and also noted to be stage selective towards the climatic factors as for the instance the tomato crop requires the specific temperature for the lycopene production and maintenance as the temperature of 20-24 °C is found to be optimum but the temperature below 10 °C during night and more than 30°C will lead for dropping down of its production and ultimately the hotter surroundings with 40°C will full breakdown the lycopene and makes the appearance inferior. The wild relative are trusted to be the final resort for the resistant genes for these adverse climate conditions as these wild relatives are themselves evolved in the challenging climates. Hence, incorporation of the wild *capsicum xyloglucan endotransglucosylase/hydrolase (CaXTH3)* gene into cultivated forms and reported tolerance towards salinity and drought. Wild types of okra (*A. tetraphyllum*) are found to be efficient to incorporate the drought tolerant gene to cultivated farms [51]. Suma et al. [52] confirmed the importance of the use of wild species (*Abelmoschus pungens* var. *mizoramensis*, *A. enbeepееееarensis*, *A. caillei*, *A. tetraphyllum* and *A. angulosus* var. *grandiflorus*) for introgressing the adoptability traits for adverse growing situations. The continuously changing climate is found to affect the crop growing areas there by impacting the shift in crop cultivation to non-agriculture side Fumia et al. [53] performed a simulation study and inferred that the potato wild relatives (*Solanum gracilifrons* and *Solanum salasianum*) would be the source of genes to fight against changing climatic specifications. The wild potato species *S. chacoense* and *S. commersonii* reported to be imparting the high temperature tolerance to the introgressed crop. *S. melameanum* is found to be the source for freezing tolerant genes that can withstand -5°C [54]. As like other crop carrot also susceptible for biotic stress for certain extent, the wild relative of carrot i.e., *Daucus carota* L. subsp. *capillifolius* can be used as donor for drought and heat sustenance [31]. The starchy root crop cassava (*Manihot esculenta*) is found to be compatible with its progenitor species *M. esculenta* ssp. *flabellifolia* rendering it to be successfully grown in water logging area. *Lactuca serriola* the wild relative of the lettuce reported to be useful in crop improvement against salinity and drought since, the wild genes that are confirmed with SNP (single nucleotide polymorphic) markers to have six QTLs that are associated with the deposition of mineral ions on roots of crop rendering adoptability [55]. Tomatoes are found to be very sensitive to the herbicides sprayed,

this can be solved by incorporating the gene that is prominent in the biosynthesis of 7-epizingiberene the form of sesquiterpene, *S. habrochaites* the wild form of tomato is found very eminent in making cultivated tomatoes herbivore resistant and this wild species can also efficiently improve the quality traits of tomatoes like improved antioxidant activity, improved DPPH (2,2-Diphenyl-1-picrylhydrazyl) radical scavenging activity combined with higher phenols and flavonoids [56].

3. Strategies to Use Wild-farms

Though the wild relatives are found to be having the greater significance in the vegetable improvement they are considered to be the last resort of the crop improvement. The main reason for this are the barriers present in the way of using the wild farms in crop improvement. The distant hybridization is found to be hindered due to pre-syngamic and post-syngamic difficulties which are recorded to be incompatibility (genetic and genomic) and barrier (ploidy level, crossability and hybrid sterility). The failure in the success of wide hybridization involving wild farms may be due to the factors that the lack of fertilization, inability of the pollen tube to reach the embryo sac, failure in the formation of the zygote, death of zygote after formation. To overcome this many ways are found to be efficient in getting wide hybridization successful. Among many of the techniques the breeding strategies like protoplast fusion, embryo rescue through embryo culture, in-vitro methodologies (anther culture, pollen culture and haploid rising), bridge mating and grafting are found to be efficient [57].

3.1 Bridge Cross

Wide hybridization faces the prominent problem of failure in crosses between the wild and cultivated form, this may be due to the change in ploidy levels of both the parent in hybridization since many of the wild farms are found to be polyploids in nature this can be overcome by a strategy of employing the bridge crosses. Manzur et al. [58] overcome the cross incompatibility between *cucurbita* species by employing the *cucurbita undelliana* as a bridge species for the transfer of bush habit from *C. pepo* to *C. moschata* and *C. maxima* and these interspecific hybrids were also found to be multiple disease resistant. Parry et al. [59] noted that the use of *Capsicum frutescens* as a bridging species in the cross of *C. annuum* and *C. baccatum* for transfer of anthracnose resistance. The cultivated rape seed can be made *sclerotinia* resistance by transferring resistance genes from wild *Brassica incana* by the use of *Brassica napus* as a bridging species [60]. The usage of this bridge crosses demands the in depth knowledge of the intermediate species that are compatible with both wild and cultivated form facilitating the transfer of targeted gene from wild to cultivated relatives, in this regard there is a need of studying the available genetic resources both cultivated and wild farms and their crossability and this can be achieved by the molecular analysis using wide range of molecular marker for diversity analysis.

3.2 Somatic Hybridization/ Protoplast Fusion

Many of the wild farms are also found to be not crossable with the cultivated ones, this can be dealt with the somatic hybridization or protoplast fusion, where the excised protoplast of both the parents are made to fuse outside the seed parent. Protoplast fusion between *Solanum melangena* and *Solanum torvum* that showed resistance to the *verticillium* wilt. Somatic hybrids resulting by the symmetric fusion of two protoplast from the wild species found to be of great importance in the crop improvement, hybridized the protoplasts of *Solanum integrifolium* and *S. sanitwongsei* employing the

electro fusion method and the resulting hybrids were of targeted trait viz., yield and quality and were of $2n=48$ indicating symmetric hybridization. Somatic hybridization is also helpful in regeneration of the intergeneric species, *Alternariabrassicae* the devastating disease of brassica family does not has any resistant sour in its species or genera. However, the somatic hybridization between the *Brassicaoleracea* and *Camelina sativa* (false flax) found to be imparting the resistance to *alternari*. Not only in the crop improvement but this somatic hybridization also has its part in the creation of the new species like pomato, this was done with the intension of getting tomato fruits and potato tubers in single plant but the results were opposite to breeder's expectations. The resistance against the *Phytophthorainfestans* from the wild *Solanummichoacanum* can be transferred to cultivated diploid potato through somatic fusion.

3.3 Embryo Rescue

If at all the hybridization is achieved through bridge crosses, manipulating the pollinating organs (pistil and stigma) of wild and cultivating farms to facilitate hybridization [37], there exist the challenges regarding the formation and survival of the embryo. This can be dealt with the procedures like embryo culture which also referred to as embryo rescue as it saves the denaturing embryo through in-vitro procedures. The wild relatives of tomato as like others also shown the embryo degeneration after 25 day of fertilization in between *Solanum lycopersicum*, and *S. peruvianum*, this is abated by the embryo rescue of the cross on MS (Murashige and Skoog's) media and the hybridity being confirmed using RAPD markers. Though the success of embryo rescue is well documented in many interspecific crosses, this strategy also depends on some specification like age of recued embryo, shape of embryo etc., in interspecific hybridization of *Brassicarapa* × *B. oleracea* rectified that the embryo rescue after pollination at cotyledonary stage gave better results, Zaman and Parihar[61] also proved the embryo culture of the cross between the cultivated and wild forms led to improvement of okra verities resistant to YVMV diseases.

3.4 Ploidy Alteration

The variation in ploidy levels of the wild and cultivated crops also is regarded as the threat for the crossability, this demands the techniques that can alter the ploidy level of the candidate species in distant hybridization, the on chemical is widely used in the alteration of ploidy levels is colchicine ($C_{22}H_{27}O_6N$). The colchicine treatment at 0.1% for F_1 of the cross *Abelmoschus esculentus* and *A. manihot* subsp. *Tetraphyllus* was found to be efficient in overcoming the hybrid sterility in the cross [62].

3.5 Grafting

Although all the above mentioned strategies are found to have proved their efficiency to overcome the challenges that are in the way of distant hybridization that involve gametes of the parents some are found still challenging in terms of tediousness and special requirements. One of the strategy that is comparatively easier and effective being the grafting, where the cultivated farms are grafted on the rootstocks of wild relatives. To achieve the highest yield, quality and growth of brinjal cultivars the grafting over the wild rootstocks of *Solanum khasianum* and *Solanum torvum* were found to be suitable [13]. Performance of the grafted globe artichoke on the wild cordon and found to have resistance for *verticillium* wilt. Most of the wild farms of brinjal were found to impart the quality and resistance traits

on grafting which were of incompatible reactions on hybridization [63]. Thangamani et al. [39] also evidenced that the usage of wild relatives gave a good results compared to distant hybridization in making cultivated form resistant to disease and pest and of superior quality in cucumber.

4. Conclusion

Wild relatives are found to be very useful in the vegetable improvement regarding the yielding capacity, enhanced quality, improved resistance towards biotic and abiotic stress. Usage of these wild relatives in improvement of vegetable crops also shown a considerable increment in the targeted traits. The effective usage of these wild types in the vegetable improvement demands some basic requirement like knowledge about the existing wild diversity of the concerned vegetable crop, knowledge of cross compatibility and incompatibility reaction in between cultivated and their wild relatives, some negative issues linked with the wild farms of vegetable crops as some wild forms are also found to associated with high toxic compounds that may resulting in inedibility of the produce and barriers or problems in the usage of wild types in vegetable improvement, available strategies and their application in course of developing improved varieties etc., before using any wild farms in the crop improvement there should be an account of wild genetic diversity and also this demands the efforts for conserving the wild farms of cultivated vegetable types. The efficiency of the wild relative in the improvement of cultivated crop diversity is all the way proven, however due to overexploitation of these wild farms by human is challenging their existence as a consequence for genetic drift etc., factors, hence there is an urgent need of conserving these wild farms.

5. REFERENCE

1. Jaiswal AK, editor. Nutritional composition and antioxidant properties of fruits and vegetables. Academic Press; 2020.
2. Sun Y, Guo L, Zhu QH, Fan L. When domestication bottleneck meets weed. *Mol Plant*. 2022;15(9):1405-08.
3. Wellman FL, editor. Tropical American plant disease. Scarecrow Press: Metuchen;1972.
4. Bleeker PM, Mirabella R, Diergaarde PJ, VanDoorn A, Tissier A, Kant MR, et al., Improved herbivore resistance in cultivated tomato with the sesquiterpene biosynthetic pathway from a wild relative. *Proc Natl Acad Sci*.2012;109(49):20124-29. <https://www.pnas.org/cgi/doi/10.1073/pnas.1208756109>
5. Haggard JE, St. Clair DA. Combining ability for *Phytophthora infestans* quantitative resistance from wild tomato. *Crop Sci*.2015;55(1):240–54. <https://doi.org/10.2135/cropsci2014.04.0286>
6. Szymanski J, Bocobza S, Panda S, Sonawane P, Cardenas PD, Lashbrooke J, et al., Analysis of wild tomato introgression lines elucidates the genetic basis of transcriptome and metabolome variation underlying fruit traits and pathogen response. *Nature Genet*.2020;52(10):1111–21. <https://doi.org/10.1038/s41588-020-0690-6>
7. Sun YD, Liang Y, Wu JM, Li YZ, Cui X, Qin L. Dynamic QTL analysis for fruit lycopene content and total soluble solid content in a *Solanum lycopersicum* x *S. pimpinellifolium* cross. *GenetMolRes*. 2012;11(4):3696-710.
8. Pailles Y, Awlia M, Julkowska M, Passone L, Zemouri K, Negrão S, et al., Diverse traits contribute to salinity tolerance of wild tomato seedlings from the Galapagos Islands. *Plantphysiol*. 2020;182(1):534-46.
9. Roldan MVG, Périlleux C, Morin H, Huerga-Fernandez S, Latrasse D, Benhamed M, et al., Natural and induced loss of function mutations in *SIMBP21* MADS-box gene led to jointless-2 phenotype in tomato. *Sci Rep*. 2017;7(1):4402.
10. Neuman H, Galpaz N, Cunningham Jr FX, Zamir D, Hirschberg J. The tomato mutation *nxd1* reveals a gene necessary for neoxanthin biosynthesis and demonstrates that violaxanthin is a sufficient precursor for abscisic acid biosynthesis. *PlantJ*. 2014;78(1):80-93.

11. Brog YM, Osorio S, Yichie Y, Alseekh S, Bensal E, Kochevenko A, et al., A *Solanumneorickii* introgression population providing a powerful complement to the extensively characterized *Solanumpennellii* population. *PlantJ*. 2019;97(2):391-403.
12. Taher D, Ramasamy S, Prohens J, Rakha M. Screening cultivated eggplant and wild relatives for resistance to sweet potato whitefly (*Bemisiatabaci*) and to two-spotted spider mite (*Tetranychusurticae*). *Euphytica*.2020;216:1-13.
13. Kumar BA, Pandey AK, Raja P, Singh S, Wangchu L. Grafting in Brinjal (*Solanummelongena* L.) for growth, yield and quality attributes. *Int j bio-resour stress manag*. 2017;8(5):611-16. <https://doi.org/10.23910/JBSM/2017.8.5.1840a>
14. Kaur J, Sidhu MK, Sarao NK, Dhatt, A. Development of inter-specific hybrids between *Solanummelongena* L. and *Solanumsisymbriifolium* Lam. through embryo rescue. *IndianJ GenetPlantBreed*. 2023;83(03):414-21.
15. Koffi-Nevry R, Kouassi KC, Nanga ZY, Koussémon M, Loukou GY. Antibacterial activity of two bell pepper extracts: *Capsicumannuum* L. and *Capsicumfrutescens*. *IntJfoodprop*.2012;15(5):961-71.
16. Oboh G, Rocha JBT. Distribution and antioxidant activity of polyphenols in ripe and unripe tree pepper (*Capsicumpubescens*). *J Food Biochem*. 2007;31(4):456-73.
17. Ross H. The use of wild *Solanum* species in German potato breeding of the past and today. *Am J Potato Res*.1966;43:63–80. <https://doi.org/10.1007/BF02861579>
18. Upadhy MD, Khushu CL, Bhattacharjee SK, Ray S. Breeding potato varieties for charcoal rot (PL 480 Project). In: Final technical report. Central Potato Research Institute, Shimla, India. 1977.
19. Sharma KP, Pandey SK, Tyagi BR.Editors. Breeding for field resistance to late blight of potato. Central Potato Research Institute Shimla. 92–95; 1982.
20. Hamernik AJ, Hanneman RE, Jansky SH. Introgression of wild species germplasm with extreme resistance to cold sweetening into the cultivated potato. *Crop Sci*.2009;49(2):529–42. <https://doi.org/10.2135/cropsci2008.04.0209>
21. Su Y, Viquez ZM, den Uil D, Sinnige J, Kruyt H, van VossenJ, HS. Introgression of genes for resistance against *Phytophthora infestans* in diploid potato. *Am J Potato Res*.2020;97(1):33–42. <https://doi.org/10.1007/s12230-019-09741-8>
22. Chand D, Dikshit N, Sivaraj N, Gomashe SS, Nizar MA. Diversity assessment in *Abelmoschustuberculatus*: A DIVA-GIS study. *J Environ Biol*.2018;39(4):426-31.
23. Rubiang-Yalambing L, Arcot, J, Greenfield H, Holford P.Aibika (*Abelmoschusmanihot* L.): Genetic variation, morphology and relationships to micronutrient composition. *Food Chem*.2016;193:62-68.
24. Tonguç M, Griffiths PD. Transfer of powdery mildew resistance from *Brassica carinata* to *Brassica oleracea* through embryo rescue. *Plant Breed*. 2004;123(6):587-9.
25. Chevre AM, Eber F, This P, Barret P, Tanguy X, Brun H, et al., Characterization of *Brassica nigra* chromosomes and of blackleg resistance in *B. napus*—*B. nigra* addition lines. *Plant Breed*.1996;115(2):113-8.
26. Mohapatra D, Bajaj YPS. Interspecific hybridization in *Brassica juncea*—*Brassica hirta* using embryo rescue. *Euphytica*.1987;36(1):321-26.
27. Yamagishi H, Bhat SR. Cytoplasmic male sterility in Brassicaceae crops. *Breed Sci*. 2014;64(1):38-47.
28. Friedt W, Tu J, Fu T. Academic and economic importance of *Brassica napus* rapeseed. In: Liu S, Snowdon R, Chalhoub B editors. The *Brassica napus* genome. Cham, Switzerland: Springer; 2018.
29. Jung C, Wehling P, Löptien H. Electrophoretic investigations on nematode resistant sugar beets. *Plant Breed*.1986;97:39–45. <https://doi.org/10.1111/j.1439-0523.1986.tb01299.x>
30. Biancardi E, Panella LW, Lewellen RT.Editors. *Beta Maritima*. The Origin of Beets. New York, NY: Springer; 2012.
31. Simon PW, Rolling WR, Senalik D, Bolton AL, Rahim MA, Mannan AM, et al., Wild carrot diversity for new sources of abiotic stress tolerance to strengthen vegetable breeding in Bangladesh and Pakistan. *Crop Sci*. 2021;61(1):163-76. <https://doi.org/10.1002/csc2.20333>
32. Yoshida J, Tomooka N, Yee KT, Shantha PGS, Naito H, Matsuda Y. Unique responses of three highly salt tolerant wild *Vigna* species against salt stress. *Plant Prod Sci*.2020;23:1–15. <https://doi.org/10.1080/1343943X.2019.1698968>
33. Pal SS, Singh JJ, Singh I. Transfer of YMV resistance in cultivar SML32 of *Vigna radiata* from other related *Vigna* species. *Res Plant Dis*.2000;15:67–69

34. Van Zonneveld M, Rakha M, Tan SY, Chou YY, Chang CH, Yen JY, et al., Mapping patterns of abiotic and biotic stress resilience uncovers conservation gaps and breeding potential of *Vigna* wild relatives. *Scirep*. 2020;10(1):2111.
35. Abdallah F, Kumar S, Amri A, Mentag R, Kehel Z, Amri MRK. Wild *Lathyrus* species as a great source of resistance for introgression into cultivated grass pea (*Lathyrus sativus* L.) against broomrape weeds (*Orobanche crenata* Forsk. and *Orobanchefoetida* Poir). *Crop Sci*.2021;61:263–76. <https://doi.org/10.1002/csc2.20399>
36. Bhatt L, Nautiyal MK, Choudhary DR. Genetic analysis for multiple fruit yield and its attributing traits in eggplant (*Solanum melongena* L.) used as wild species *Solanum gilo* as male parent under tarai conditions of Uttarakhand. Dissertation, Govind Ballabh Pant University of Agriculture & Technology. India; 2023.<https://doi.org/10.21203/rs.3.rs-2502169/v1>
37. Singh S, Bhatia R, Kumar R, Das A, Ghemeray H, Behera TK, Dey SS. Characterization and genetic analysis of OguCMS and doubled haploid based large genetic arsenal of Indian cauliflowers (*Brassica oleracea* var. *botrytis* L.) for morphological, reproductive and seed yield traits revealed their breeding potential. *Genet Resour Crop Evol*. 2021;68:1603-23.
38. Tan J, Tao Q, Niu H, Zhang Z, Li D, Gong Z, Weng Y, Li Z. A novel allele of monoecious (*m*) locus is responsible for elongated fruit shape and perfect flowers in cucumber (*Cucumis sativus* L.). *Theor Appl Genet*.2015;128:2483-93.
39. Thangamani C, Pugalendhi L, Jaya Jasmine A, Punithaveni V. Grafting techniques in cucumber using wild and cultivated cucurbits as rootstocks. In III International Symposium on Underutilized Plant Species.2015;1241:407-12.
40. Ghani MA, Abbas MM, Amjad M, Ziaf K, Ali B, Shaheen T, Awan FS, Khan AN. Production and characterisation of tomato derived from interspecific hybridisation between cultivated tomato and its wild relatives. *J Hortic Sci Biotechnol*. 2020;95(4):506-20. <https://doi.org/10.1080/14620316.2019.1689182>
41. Wang GX, Lv J, Zhang J, Han S, Zong M, Guo N, et al., Genetic and epigenetic alterations of *Brassicainigra* introgression lines from somatic hybridization: a resource for cauliflower improvement. *Front Plant Sci*. 2016;7:1258.
42. Kumar R, Meena JK, Yadav N. Breeding cucumber for quality improvement. *Int J Farm Sci*. 2017;7(1): 54-56.
43. Wu S, Lau KH, Cao Q, Hamilton JP, Sun H, Zhou C, Eserman L, et al., Genome sequences of two diploid wild relatives of cultivated sweet potato reveal targets for genetic improvement. *NatCommun*. 2018;9(1):4580. <https://doi.org/10.1038/s41467-018-06983-8>
44. Gramazio P, Takayama M, Ezura H. Challenges and prospects of new plant breeding techniques for GABA improvement in crops: tomato as an example. *FrontPlantSci*. 2020;11:577980. <https://doi.org/10.3389/fpls.2020.577980>
45. Karim KMR, Rafii YM, Misran AB, Ismail MFB, Khan MMH, Chowdhury MFN. Current and Prospective Strategies in the Varietal Improvement of Chilli (*Capsicum annum* L.) Specially Heterosis Breeding. *Agron*.2021;11:2217. <https://doi.org/10.3390/agronomy11112217>
46. Srivastava A, Mangal M, Mandal B, Sharma VK, Tomar BS. *Solanumpseudocapsicum*: wild source of resistance to Chilli leaf curl disease. *Physiol Mol Plant Pathol*. 2021;113:101566.
47. Shaukat MA, Ahmad A, Mustafa F. Evaluation of resistance in brinjal (*Solanum melongena* L.) against brinjal shoot and fruit borer (*Leucinodes orbonalis* Guen.) infestation. *Int j appl sci biotechnol*. 2018;6(3):199-206.
48. Anyaoha CO, Arogundade O, Akinkunmi OY, Okoyo ME, Ikoro JI. Agro-morphological characterization of Okra (*Abelmoschus* species) for biotic stress and yield contributing traits under rainfed conditions in South Western Nigeria. *Plant Physiol Rep*. 2023;28(1):92-106. <https://doi.org/10.1007/s40502-023-00716-w>
49. Perez W, Alarcon L, Rojas T, Correa Y, Juarez H, Andrade-Piedra JL, et al., Screening South American potato landraces and potato wild relatives for novel sources of late blight resistance. *Plant Dis*. 2022;106(7):1845-1856. <https://doi.org/10.1094/PDIS-07-21-1582-RE>
50. Ordoñez B, Aponte M, Lindqvist-Kreuzer H, Bonierbale M. A case study of potato germplasm enhancement using distant late blight resistant wild relatives. *Crop Sci*.2023;63:2699–2712. <https://doi.org/10.1002/csc2.21038>
51. Mkhabela SS, Shimelis H, Gerrano AS, Mashilo J, Shayanowako A. Characterization of Okra (*Abelmoschus esculentus* L.) Accessions with Variable Drought Tolerance through Simple Sequence Repeat Markers and Phenotypic Traits. *Diversity*. 2022;14(9):747.

52. Suma A, Joseph John K, Bhat KV, Latha M, Lakshmi CJ, et al., Genetic enhancement of okra [*Abelmoschus esculentus* (L.) Moench] germplasm through wide hybridization. *Front Plant Sci.* 2023;14:1284070. <https://doi.org/10.3389/fpls.2023.1284070>
53. Fumia N, Pironon S, Rubinoff D, Khoury CK, Gore MA, Kantar MB. Wild relatives of potato may bolster its adaptation to new niches under future climate scenarios. *Food Energy Secur.* 2022;11(2):360. <https://doi.org/10.1002/fes3.360>
54. Nicolao R, Gaiero P, Castro CM, Heiden G. *Solanum malmeanum*, a promising wild relative for potato breeding. *Front Plant Sci.* 2023;3:1-16. <https://doi.org/10.3389/fpls.2022.1046702>
55. Uwimana B, Smulders MJ, Hoofman DA, Hartman Y, van Tienderen PH, Jansen J, et al., Hybridization between crops and wild relatives: the contribution of cultivated lettuce to the vigour of crop-wild hybrids under drought, salinity and nutrient deficiency conditions. *Theor Appl Genet.* 2012;125:1097-1111. <https://doi.org/10.1007/s00122-012-1897-4>
56. Kavitha P, Shivashankara KS, Rao VK, Sadashiva AT, Ravishankar KV, Sathish GJ. Genotypic variability for antioxidant and quality parameters among tomato cultivars, hybrids, cherry tomatoes and wild species. *J Sci Food Agric.* 2014;94(5):993-99. <https://doi.org/10.1002/jsfa.6359>
57. Chauhan A, Sharma D, Banyal SK. Potential, Challenges and Strategies Involved in Gene Introgression from Wild Relatives of Vegetable Crops. *Agric Rev.* 2021;42(4):390-97
58. Manzur JP, Fita A, Prohens J, Rodriguez-Burruezo A. Successful wide hybridization and introgression breeding in a diverse set of common peppers (*Capsicum annuum*) using different cultivated Aji (*C. baccatum*) accessions as donor parents. *PLoS One.* 2015;10(12):0144142.
59. Parry C, Wang YW, Lin SW, Barchenger DW. Editors. Reproductive compatibility in capsicum is not reflected in genetic or phenotypic similarity between species complexes. *bioRxiv.* 2020.
60. Mei J, Liu Y, Wei D, Wittkop B, Ding Y, Li Q, et al., Transfer of *sclerotinia* resistance from wild relative of *Brassica oleracea* into *Brassica napus* using a hexaploidy step. *Theor Appl Genet.* 2015;128:639-44.
61. Zaman MS, Parihar A. Development of novel interspecific hybrid between cultivated and wild species of okra [*Abelmoschus esculentus* (L.) Moench] through embryo rescue. *Indian J Plant Breed.* 2023;83(03):422-32.
62. Reddy MT. Crossability behaviour and fertility restoration through colchipoity in interspecific hybrids of *Abelmoschus esculentus* × *Abelmoschus manihot* subsp. *tetraphyllus*. *Int J Plant Sci.* 2015;1(4):172-81.
63. Senthilvadivu G, Pugalendhi L, Saraswathi T, Raguchander T, Shanthi A, Jeyakumar P. Morphological Characterization of Wild *Solanum* Species Used for Grafting in Brinjal (*Solanum melongena* L.). *Madras Agric J.* 2023;110(1-3):1.