



# Breeding for Resistance against Pest and Diseases in Tomatoes: A Review

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## Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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## ABSTRACT

Diseases and pests have a substantial effect on tomato production, greatly affecting both the quantity and quality of this crucial vegetable crop. Although fungicides and insecticides have been important in controlling plant diseases and pests, their excessive usage raises significant environmental issues. Vegetable breeders are increasingly concentrating on developing cultivars with natural tolerance to biotic stresses to promote sustainability and environmental friendliness. The change in focus is intended to cultivate tomato cultivars with inherent resistance to diseases and pests, hence decreasing the need for chemical treatments. Advancements in creating high-yielding genetically resistant tomato cultivars are a result of detailed study on the genetic basis of pest and disease resistance in tomato crops, as well as the complex interactions between the host plant and pathogens. For effective breeding programs and pre-breeding activities, scientists and breeders must have access to sources of resistance and a thorough grasp of the genetic complexities involved. This requires examining the genetic composition of both the tomato plants and the different infections that are impacting them. Breeders may generate tomato cultivars with strong resistance to common diseases and pests by using the inherent defensive mechanisms found in certain tomato types via selective crossing. Continuing to study how hosts and pathogens interact and the molecular processes involved in resistance is crucial. This information offers vital insights on how to improve and expand resistance, leading to the creation of cultivars with long-lasting and wide-ranging resistance. Currently, the emphasis on breeding is a proactive and sustainable strategy for transfer of resistances in high yielding tomato cultivars. Researchers aim to develop tomato cultivars that provide high yield and demonstrate tolerance to changing disease and pest stresses by integrating genetic knowledge with sophisticated breeding methods. This comprehensive method protects tomato crops and encourages environmental sustainability by decreasing the need on chemical inputs in agriculture.

**Keywords:** *Tomato; biotic stresses; inheritance of resistance; biotechnological approaches; molecular marker; grafting; integrating genetic; vegetable crops.*

## 1. INTRODUCTION

One of the most important vegetable crops is tomato, *Solanum lycopersicum* L. (Solanaceae). The origin of tomatoes is located in South America, particularly Peru [1]. However, the major domestication of tomatoes took place in Mexico due to the availability of several cultivated and wild species of the tomato that originated in this region [2] (Fig. 1). Concerning the matter of human nutrition, it has developed into a significant commercial crop in recent years. The flavonoids, beta-carotene, lycopene, and vitamin C that it contains are among the nutrients that it offers. Furthermore, the antioxidative and anti-cancer capabilities of lycopene have contributed to the rise in popularity of tomatoes, particularly in contemporary times [3].

A paucity of genetic diversity is seen in conventionally produced tomatoes. As a result, it has been proposed that the required resistance features should be transmitted from their wild type species [4] (Fig. 2). For the purpose of regulating the expression of their target genes and orchestrating the biochemical and

physiological adjustments that are essential for stress tolerance and the modulation of plant development, transcription factors (TFs) attach themselves to their target genes upon the detection of stress [5]. The most important problem is the high number of instances of diseases and pests that come up during tomato production. The use of pesticides without discrimination in order to control diseases, nematodes and insect-pests, is harmful to both the environment and human health. In contrast, there has been virtually little progress made in the development of insect resistance over the years. Host plant resistance is the most cost-effective strategy; nevertheless, this sort of resistance against insect pests is not at all durable because of the population pressure that insects exert on the host. As a result, there is development of new biotypes and a breakdown of resistance [6].

Varieties that have been launched up to this point have been connected with one or more traits that are not desired, and as a result, they have not earned the popularity that they deserve. Vegetable yields have decreased by

around 40% due to the presence of insect pests [7].

The tomato, *S. lycopersicum* L., an economically significant crop was the first vegetable to be produced anywhere in the world. It is a model plant species due to its diploid, relatively compact, and recently sequenced genome as well as its large genetic and genomic resources [8].

Several related wild species of tomato, including *S. pennellii* and *S. habrochaites*, have been found to possess resistance to major insect pests. Among these species, *S. habrochaites* is particularly noteworthy as it serves as a significant source of arthropod resistance. Two distinct forms of *S. habrochaites*, namely *S. habrochaites* f. *glabratum* and *S. habrochaites* f.

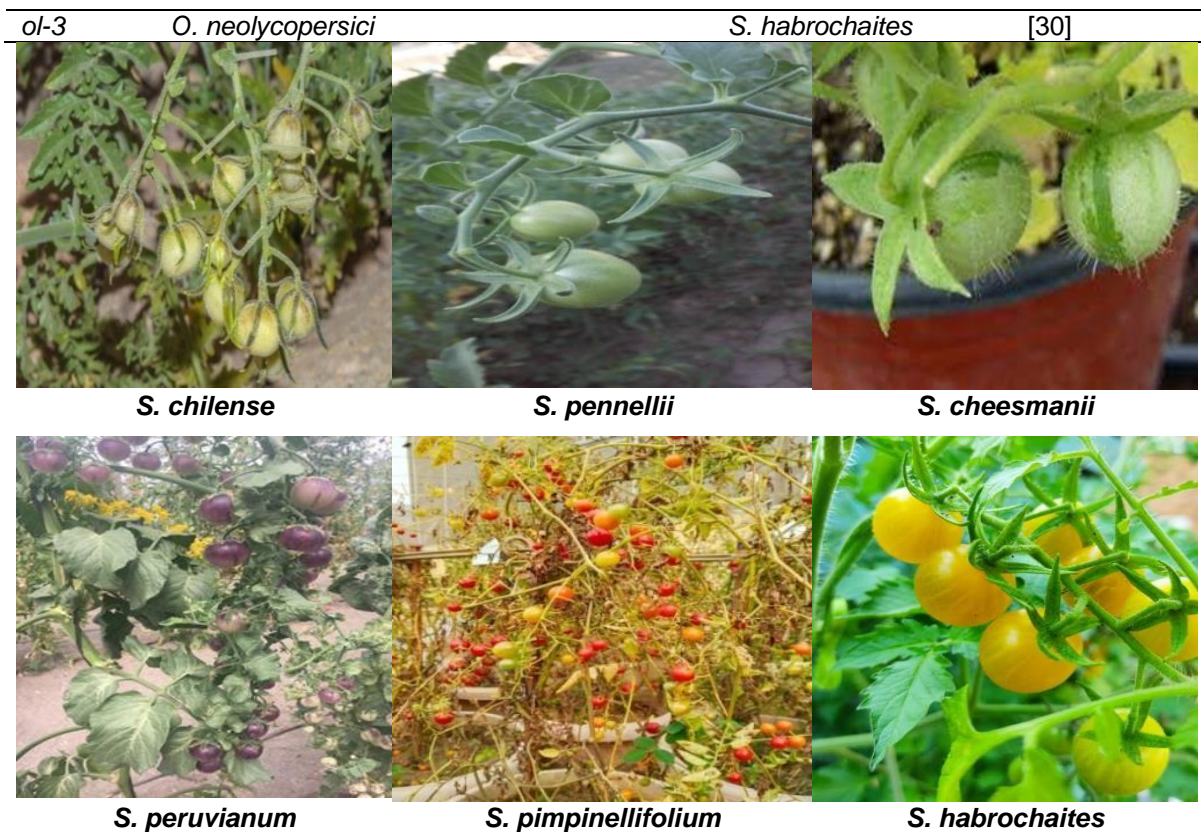
*typicum*, exhibit resistance to at least 16 pest species, as indicated in Table 1. Similarly, *S. pennellii* demonstrates resistance to a minimum of nine insect species, such as carmine, greenhouse whitefly, the potato aphid, and spider mites. Additional wild species, including *L. esculentum* var. *cerasiforme*, *S. cheesmanii*, *S. pimpinellifolium*, *S. chmielewskii*, *S. chilense*, and *S. peruvianum* exhibit different levels of resistance to insects [4]. Although these wild tomato species provide a wide range of resources for pest resistance, their whole potential has not been completely used in insect resistance breeding projects. Although there has been some research on inheritance, most of these genetic resources are not being fully used and lack proper characterization.

**Table 1. Major insect-pests and diseases of tomato in India**

Diseases	Insect-Pests	Reference
ToLCV, CMV, early blight, late blight, nematodes, root-knot, bacterial wilt (BW), tomato spotted wilt virus (ToSWV) and septoria leaf spot.	Aphid, Fruit borer and white fly	[4]

**Table 2. Resistance sources for biotic stresses in tomato**

Resistant genes	Resistance against diseases	Resistance Sources	References
<i>Asc-1</i>	<i>Alternaria alternata</i> f. sp. <i>lycopersici</i>	<i>S. lycopersicum</i>	[9]
<i>Am</i>	Alfalfa mosaic virus	<i>S. habrochaites</i>	[10]
<i>Bs4</i>	<i>Xanthomonas campestris</i>	<i>S. lycopersicum</i>	[11]
<i>Cmv</i>	Cucumber mosaic virus	<i>S. chilense</i>	[12]
<i>Cf-1</i>	<i>Cladosporium fulvum</i>	<i>S. lycopersicum</i> var <i>cerasiforme</i>	[13]
<i>Cf-2</i>	<i>C. fulvum</i>	<i>S. pimpinellifolium</i>	[14]
<i>Cf-3</i>	<i>C. fulvum</i>	<i>S. pimpinellifolium</i>	[15]
<i>Frl</i>	<i>Fusarium oxysporum</i> f.sp. <i>radicis-lycopersici</i>		[16]
<i>Hero</i>	<i>Globodera rostochiensis</i>	<i>S. pimpinellifolium</i>	[17]
<i>I</i>	<i>Fusarium oxysporum</i> formae speciales <i>lycopersici</i>	<i>S. pimpinellifolium</i>	[18]
<i>Mi-1.2</i>	<i>Meloidogyne</i> spp	<i>S. peruvianum</i>	[19]
<i>Ph-1</i>	<i>Phytophthora infestans</i>	<i>S. pimpinellifolium</i>	[20]
<i>Sw-5</i>	Tomato spotted wilt virus (ToSWV) and tomato chlorotic spot virus (ToCSV)	<i>S. peruvianum</i>	[21]
<i>Sw-7</i>	ToSWV	<i>S. chilense</i>	[22]
<i>Ve1</i>	<i>Verticillium dahliae</i>	<i>S. lycopersicum</i>	[23]
<i>Ty-1</i>	ToYLCV	<i>S. chilense</i>	[16]
<i>Ty-2</i>	ToYLCV	<i>S. habrochaites</i>	[24]
<i>Ty-3</i>	ToYLCV, ToMV	<i>S. chilense</i>	[25]
<i>Ty-4</i>	ToYLCV	<i>S. chilense</i>	[26]
	ToYLCV	<i>S. peruvianum</i>	[27]
<i>ol-1</i>	<i>Oidium neolycopersici</i>	<i>S. habrochaites</i>	[28]
<i>ol-2</i>	<i>O. neolycopersici</i>	<i>S. lycopersicum</i> var <i>cerasiforme</i>	[29]



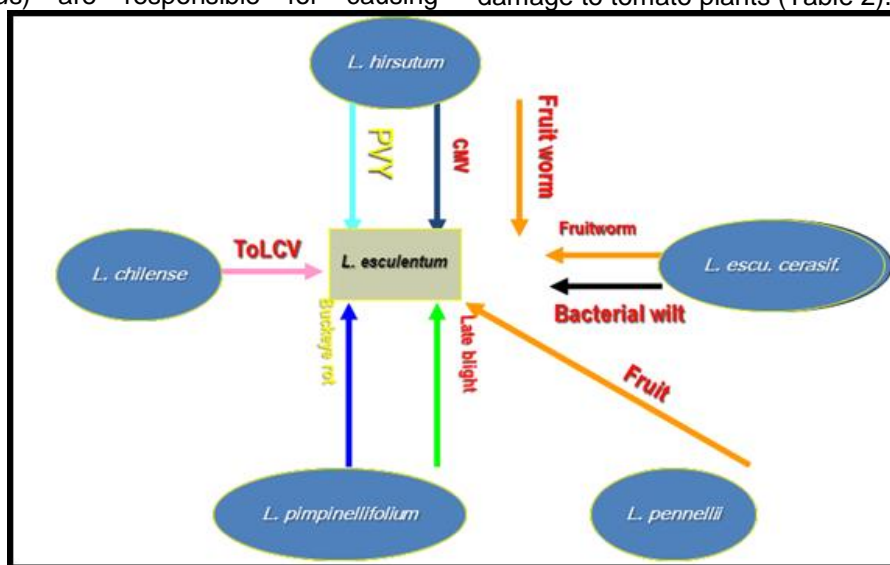
**Fig. 1. Different wild tomato species for different resistant sources**

Breeding for insect resistance in tomatoes has indeed posed more challenges compared to breeding for disease resistance. One significant obstacle that breeders face is what's known as "linkage drag." This refers to the tendency for genes controlling desirable traits, like insect resistance, to be physically close to genes that control undesirable traits or have negative effects on plant performance. The presence of linkage drag complicates the development of insect-resistant tomato cultivars because breeders must navigate through a genetic landscape where improving one trait may inadvertently introduce or perpetuate unwanted traits. This can slow down the progress of breeding programs and make it challenging to produce commercially viable insect-resistant tomato varieties.

Tomato leaf curl New Delhi virus (ToLCNDV) is a kind of bipartite begomovirus that belongs to the genus *Begomovirus* and the family Geminiviridae. The isolates of the virus are naturally transmitted by the whitefly *Bemisia tabaci* (Hemiptera: Aleyrodidae). This transmission happens in a cyclical and uninterrupted manner [31]. Research has shown that ToLCNDV, a begomovirus, has significant

economic implications since it inflicts substantial damage on tomato (*Solanum lycopersicum*) cultivation. The prevalence of this begomovirus is higher in northern India, as reported by [32,33,34] and [35]. Tomato wilt infections may be caused by several pathogens, including as nematodes, fungus, bacteria, viruses, and other biotic factors. *Fusarium oxysporum* is a diverse fungus that exists in more than one hundred various variations, each of which is often linked to a specific host and capable of causing disease. There are around one hundred distinct species of *F. oxysporum* that cause vascular wilts in flowering plants [36]. This specific fungus is a hyphomycete that is found in the soil. A variety of insects, including whiteflies (*Bemisia tabaci*), mites (*etranychus spp.*), aphids (*Aphisgossypii*), Lepidoptera (such as, beet armyworm (*Spodoptera exigua*), tomato fruitworm (*Helicoverpa zea*), cotton bollworm (*Helicoverpa armigera*), Coleoptera (such as tobacco flea beetle (*Epitrix hirtipennis*) and colorado potato beetle (*Leptinotarsa decemlineata*), Diptera (such as fruit fly (*Neoceratitis cyanescens*) and leafminers (*Tuta absoluta*), cutworms (*Peridroma saucia*), thrips (*Frankliniella occidentalis*) and sinkbugs (*Arvelius*

*albopunctatus*) are responsible for causing damage to tomato plants (Table 2).



**Fig. 2. Process of introgression of wild species in cultivated tomato**

## 2. BIOTECHNOLOGICAL INTERVENTIONS

Tomatoes have long served as a model in plant research due to their genomic characteristics and growth habits, as noted by [8]. However, despite their high diversity and genetic variability, much of the potential of tomato landraces remains untapped, primarily due to limited genetic background information and performance data across diverse climates [37]. This scarcity of information hinders the effective utilization of these varieties in breeding programs.

Traditional breeding methods for quantitative and qualitative tomato traits are known to be time taking, often taking around five years for market commercialization (Resistant to Viral Diseases; [38,39]). This lengthy process highlights the need for more efficient breeding techniques to accelerate the development of improved tomato cultivars. Recent advancements in tomato tissue culture, mutagenesis, recombinant DNA technologies, transformation protocols, and transient expression assays offer promising avenues for enhancing tomato cultivars [40,41,42] and [4]. These technologies provide alternative means to traditional breeding methods and can significantly contribute to the improvement of tomato cultivars. One notable obstacle in tomato breeding is the incompatibility between wild and cultivated tomatoes, which can impede the process of crossing and introgressing desirable traits. However, tissue culture technologies offer solutions to overcome such

barriers. Techniques like embryo rescue, in vitro cultivation, protoplast fusion, and somatic hybridization can facilitate the successful transfer of beneficial traits from wild tomato species to cultivated varieties [40].

Additionally, the process of introgression, which involves the introduction of desirable genes from wild relatives into domesticated species, may be accomplished via the use of marker-assisted breeding (Table 3). On account of the fact that the desired gene is only present in a single or a few locations across the genome, it is possible to choose against markers that indicate other regions of the wild type chromosomes. This will result in the deletion of those genes, which are often undesirable, from the offspring. There have been attempts made to generate plants that are resistant to a variety of biotic stressors, including viruses, bacteria, fungi, and insect pests, via the use of genetic engineering. Researchers have successfully developed a strong defense against Tomato mosaic virus (ToMV) infection by expressing solely the coat protein. This approach has also shown positive results in transgenic tomato plants, providing protection against several plant viruses such as Cucumber mosaic virus (CMV) and alfalfa mosaic virus [43,44]. Progress in engineering insect resistance in transgenic tomato has been achieved [45] and [46] (Table 4). Overall, the integration of modern biotechnological tools with traditional breeding methods holds immense potential for advancing tomato cultivars with improved traits, addressing challenges related to genetic



diversity, climate adaptation, and pest/disease resistance.

**Table 3. Molecular markers used in tomato**

Sr.No.	Markers type	References
1	SNP	[47], [48], [49], [50], [51], [52] and [53]
2	CAPS	[54]
3	SSR	[55], [56], [57], [49], [58] and [59]
4	AFLP	[60]
5	RFLP	[58]
6	SRAP	[61] and [56]
7	SCAR	[62]

**Table 4. Transgenes in tomato crop for resistance to viral diseases**

Transgenes	Resistant to	Reference
<i>Cp</i> gene	ToMV	[4]
<i>Cp</i> gene	ToYLCV	
Antisense RNA	ToMV	
Satellite RNA	CMV	
<i>N</i> gene	ToSWV	
Truncated C1gene	CMV	
Two <i>Cp</i> genes	CMV	

**Table 5. Resistance source of rootstock used in tomato grafting**

Resistance Source	Resistance to	References
<i>Solanum pennelli</i>	<i>Alternaria alternata</i> f. sp. <i>lycopersici</i>	[65]
<i>S. habrochaites</i>	<i>Pseudomonas syringae</i> pv. tomato race 1	[66]
<i>S. chilense</i>	CMV, ToYLCV	[67]
<i>S. neorickii</i>	<i>Botrytis cinerea</i>	[68]
<i>S. pimpinellifolium</i>	Colour, quality, resistance to BWLB	[69]
<i>S. lycopersicum</i>	Fungi and root rot	[70]
<i>S. peruvianum</i>	ToSWV and RKN	[71], [72] and [73]

### 3. GRAFTING

The production of grafted seedling vegetables was created in Japan and Korea with the intention of minimizing the amount of main crop loss that was brought about by the infection of soil-borne illnesses that were made worse by recurrent cropping. This was done with the intention of lowering the amount of main crop loss. The strong roots of the rootstock that was selected have the ability to display an unusual degree of resistance to severe soil-borne illnesses. These diseases include those that are caused by *Pseudomonas*, *Fusarium*, *Verticillium*, and *Phytophthora*. despite the fact that the degree of tolerance varies substantially

depending on the rootstocks, the plant is able to tolerate nematodes, *Monosporascus cannonballus*, and *Didymellabryoniae* [59] and [63]. Depending on the level of resistance that is present in both the scion and the rootstocks, it is feasible that virus-resistant rootstocks might have a major influence on the scion infection of some viral infections (ToMV races). This would be the case if their presence was sufficient. There is a chance that the disease resistance of grafted seedlings is purely attributed to the rootstock roots' capacity to endure infections of this sort. This is a possibility. According to the agreement that has been achieved [64] and [64], the disease-prone features of the scion are not passed to the rootstock. On the other hand, the

rootstock does not inherit the trait of being susceptible to disease.

#### 4. FUTURE STRATEGIES

Developing cultivars with resistance or tolerance to diseases and insects is crucial for reducing losses caused by these biotic stressors. While chemical control methods are effective, they are often costly and can have long-lasting environmental impacts. Therefore, active research programs are essential to tap into the genetic diversity of existing germplasm, especially wild relatives, to create pre-bred lines with potential resistance traits. Efficient techniques for artificial inoculation of plantlets can greatly enhance the breeding process for disease and pest resistance. Gene pyramiding, combining multiple resistance genes into hybrids or varieties, is another important strategy to combat a range of biotic stressors effectively. Priority should be given to breeding efforts targeting integrated diseases and insect pests, such as TMV and leaf curl in tomatoes, to achieve optimal outcomes. Collaborative efforts between breeders and plant pathologists or entomologists are crucial for addressing these challenges effectively.

#### 5. CONCLUSION

As a conclusion, the process of developing resistance to pests and diseases in tomatoes involves a comprehensive and integrated strategy. By combining conventional breeding methods with advanced biotechnological tools, substantial advancements have been achieved in the development of tomato varieties with improved resistance characteristics. The incorporation of genetic diversity from wild tomato species has played a crucial role in transferring new resistance genes into cultivated variants. In addition, progress in molecular breeding techniques, such as marker-assisted selection and genetic engineering, has accelerated the creation of cultivars that are resistant to diseases or pests. Nevertheless, there are ongoing difficulties that need to be addressed, such as the appearance of novel pest and disease strains, the genetic diversity within pathogen populations, and the need for sustainable and ecologically sound remedies. To overcome these issues and ensure the long-term success of tomato resistance breeding programs, it is necessary to continue research efforts that concentrate on understanding plant-pathogen interactions,

improving breeding procedures, and fostering genetic diversity.

#### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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