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GENES AND ASSOCIATED MOLECULAR MARKERS CONFERRING THE RESISTANCE FOR MAJOR BACTERIAL DISEASES OF TOMATO (*Solanum Lycopersicum* L.)

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Introduction

Tomato is one of the most important vegetable crops which cultivated though the world. Most of the tomato cultivars are highly susceptible to the bacterial diseases except some wild races and germplasm. Several bacterial diseases *viz.* bacterial wilt; bacterial cancer, bacterial specks and bacterial spot may directly influence the tomato cultivation across the world. Bacterial diseases of tomato are common in all season. Most of the bacterial diseases of tomato and other solanaceous vegetables are weather specific. They are prominent under suitable environmental conditions. The damage from bacterial diseases is ranged from upper ground to underground portion of the plants. Bacterial diseases of tomato affects entire plants including leaves, stems, fruits and finally reduces the economic yield. Management of tomato bacterial diseases focused with prevention during seedling establishment to transplanting. Strategic breeding with the interference of molecular tools and techniques is one of the marvelous ways to improve the tomato cultivars for various bacterial diseases.

Molecular markers based breeding for the incorporation of desirable traits conferring the resistance for biotic threats is one of the powerful tools in tomato breeding programmes. In the tomato breeding programme for development of disease resistant tomato cultivars, wild tomato species are the wide source of resistance gene. A huge collection of tomato wild species and their relatives, number of candidate genes have been identified and validated using gene linked and gene based molecular markers again disease resistance. DNA markers have wide range of plant species including tomato. Use of molecular markers in the construction of high-density linkage maps are a useful tools for association analysis, QTL analysis and marker assisted backcross breeding. However, the development of large number of molecular markers for saturation of the linkage map with respect to particular traits and use in the identification of candidate resistance genes may determine the future breeding strategy for development of disease resistant tomato cultivars (Jehan, *et al*., 2016).

The resistance genes for various mapping population derived lines may confer the various forms for mapping populations. Some of the identified candidate genes have been validated using DNA markers could be useful for marker assisted breeding. Several functional markers have been found across the 12 chromosome of the tomato genome conferring the availability of resistance genes for various biotic threads (Rodríguez *et al*., 2011). In this article, we have discussed about the candidate resistance genes(S), linked QTLs and associated molecular markers linked to the particular genes for resistance against bacteria in tomato cultivars. This article will be useful to the tomato breeders for development of bacterial disease resistance cultivars of the tomato employing marker assisted breeding for

gene pyramiding and also in the development of breeding lines like RILs, NILs and segregation analysis in future breeding programmes.

Major bacterial diseases and genes/molecular markers conferring the resistance

The plant of entire tomato is infected by various bacterial diseases and decreases in the yield have been reported by several bacterial diseases. Bacterial wilt, bacterial spot, bacterial speck and bacterial cancer are the major diseases of tomato. Number of molecular markers associated to these bacterial diseases have been reported from tomato genome on the different chromosomal locations and some of the markers are closely linked to the particular genes which conferring the resistance. However, breeders are used molecular markers in the breeding purpose for introgression of several major and minor genes from wild species to cultivated species to achieve durable resistance for the diseases. The identified wild resistance source, resistance genes, chromosomal location of the resistance genes and linked molecular markers are given in the table.

(i) Bacterial Wilt: The bacterial wilt symptom on the tomato plant is frequently observed in the temperate zone of the world**.** Bacterial wilt of tomato is caused by *Ralstonia solanacearum.* Bacterial wilt is a devastating disease of the other solanaceous vegetable crops as well as wide range of the ornamentals in the tropical and sub-tropical region of the world. Bacterial wilt of tomato is soil born disease of the cultivated tomato genotypes. The initial stage of the disease appears on the younger leaves of the plants. Affected plants may show the wilting symptoms. Severity of the bacterial wilt prevents the supply of water and nutrient by clogging the vascular tissue within the stem. The disease develops in high temperature and moist soil. Bacterial wilt can be very difficult to manage due to lack of appropriate chemicals. It can be manage only by the cultural practices by removing of infected plants from field and crop rotation. Severity of the bacterial wilt prevents the water and nutrient supply by clogging the vascular tissue within the stem. Mainly two genes *Bwr-6* and *Bwr-12* have been have been reported from *S. lycopersicum* on the chromosome 6 and 12 respectively. These resistant genes are linked with several SCAR markers and some SNPs are also reported for these genes (Kim, *et al*., 2018).

Bacterial Wilt of Tomato

(ii) Bacterial speck: Bacterial speck is another bacterial disease of the cultivated tomato which affects the crop in both controlled and uncontrolled condition. The symptoms of the bacterial specks are appears on the fruits, leaves and later on the plants. The symptoms appear on the leaves consist of small black specks and they are more prominent on the underside leaves. The spots on the fruits are very small in size and do not penetrate deeply inside the fruit tissue. The bacterial speck of the tomato is more actives in the cool weather when the temperature is around 36^{o}F to 75 ^{o}F. It can be transferred from one plant to other plants via water through rain or sprinkler irrigation. The bacterial speck disease of the tomato can be managed by using high quality pathogen free seeds. To prevent bacterial speck of the tomato do not use sprinkler for the irrigation. They are transmitted through gardening tools

and plant debris. Bacterial speck resistance varieties of the tomatoes can be developed by using molecular tools and techniques. Resistance genes (*Pto*, *Prf*, *Fen* and *Pti1)* for bacterial speck have been identified from the wild sources. The wild source *S. pimpinellifolium* and *S. lycopersicum* are the major donor source for the bacterial speck disease and they are closely linked with the CAPS marker system (Yang, *et al.*, 2005).

Bacterial Speck of Tomato

(iii) Bacterial cancer: Bacterial cancer is well known disease of the cultivated tomato and other solanaceous vegetable crops. Bacterial cancer of tomato is caused by the gram-positive bacterium *Clavibacter michiganensis* sub-sp. *Clavibacter michiganensis.* Bacterial cancer severely infected the tomato crops in cold season due to low temperature. Marginal necrosis and tan to dark necrotic patches on the stems and leaves are the major symptoms of the bacterial cancer disease of tomato and other solanaceous vegetable crops. The small dark spot on the fruits surrounded by white halo spots are the characteristics of the bacterial cancer disease. The bacterial cancer of the tomato can be transmitted due to the overhead irrigation during seedling establishment. They are also transmitted rainfall under open environmental condition. Genes and QTLs have been indentified from the wild tomato source *Solanum peruvianum* and *S. lycopersicum* which conferring the resistance for the bacterial cancer disease of the tomato. The informative gene based RFLP marker system conferring the resistance for the bacterial cancer disease have been identified and reported (Balaji, *et al*., 2008).

Bacterial Cancer of Tomato

(iv) Bacterial spot: Bacterial spot of tomato is one of the devastating disease which affects all above ground parts of the tomato plant, including leaves, stems and fruits. Bacterial spot is the well known disease of the tomato because of the loss in yield across the world. Bacterial spot is caused by bacterium *Xanthomonas campestris* pv. *Vesicatoria* (*Xcv). Xanthomonas campestris* is the gram-negative bacteria, difficult to control due to the complex genetic background. However, several genes (*Rx-1, Rx-3, Rx-4, Rx-4, Xv-3, Bs-4, Xv-4*) have been reported. The QTLs (*Bac-spo-QTL*) has also been reported from *S. lycopersicum* var. *cerasiformae* on chromosome 11 with the help of tightly linked SSR marker system (Hutton, *et al*., 2010). The resistant gene *Rx-1* and *Rx-2* have been reported in *S. lycopersicum* on chromosome 1, 2 respectively *Rx-4* and *Xv-3* on chromosome 11 (Wang, *et al*., 2018) and *Rx-3&Bs-5* on chromosome 5 of *S. lycopersicum* (Schornack S, *et al*., 2004). These resistant genes are linked with the series of molecular markers like CAPS, InDel (Pei,*et al*., 2012).

Bacterial Spot of Tomato

Disease	Resistance gene	Linked markers	Chromosomal location of genes	Resistant source
Bacterial wilt	*Bwr-6*	---	6	*S. lycopersicum*
	Bwr-12	SNP, SCAR	12	*S. lycopersicum*
Bacterial speck	*Prf, Fen*	RLP RES	5	*S. pimpinellifolium*
	Pto	CAPS	6	*S. pimpinellifolium*
	Pti1	Other RES	12	*S. lycopersicum*
Bacterial canker	*Cmm 0.1 to 1.1*	RFLP	1,6,7,8	*S. lycopersicum*
Bacterial spot	*Rx-1. Rx-2*	---	1,2	*S. lycopersicum*
	Rx-3, Bs-4	CAPS	5	*S. lycopersicum*
	Rx-4, Xv-3	InDel, CAPS	11	*S. lycopersicum*
	Xv-4	CAPS	3	*S. lycopersicum*
	Bac-sp-QTL	SSR	11	*S. lycopersicum* var. *cerasiformae*

Table: Bacterial diseases of tomato and resistance source

Conclusion and future perspectives: The use and proper utilization of the molecular markers in tomato breeding for bacterial disease resistance would be proven as marvelous gift. It is concluded that from this literature, the wild species of tomatoes have number of resistance genes and genes conferring the resistance for bacterial diseases. However, the molecular markers are frequently available for the various gene governing the resistance for diseases caused by bacteria should must be helpful in marker assisted breeding and gene pyramiding of several major and minor genes to achieve durable resistance in the future breeding programmes.

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