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Review

Breeding tomato (*Solanum lycopersicum* L.) for resistance to biotic and abiotic stresses

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ABSTRACT

Tomato (*Solanum lycopersicum* L.) is an important vegetable crop cultivated in the tropical and sub-tropical regions of the world. Low productivity in India is due to occurrence of both biotic and abiotic stresses. Among the biotic stresses, tomato leaf curl disease, bacterial wilt, early blight and Groundnut Bud Necrosis Virus disease have become serious production constraints causing considerable yield loss in the major tomato growing areas of the country. Adoption of multiple disease resistant varieties or F_1 hybrids would be the most appropriate way to address these diseases. At ICAR-IIHR, Bengaluru systematic breeding strategies were employed to pyramid genes for resistance to early blight, bacterial wilt and tomato leaf curl diseases and to develop advanced breeding lines& F_1 hybrids with triple disease resistance. Stable source of resistance to early blight and bi-partite begomo-virus (Tomato Leaf Curl New Delhi Virus) has been identified in *Solanum habrochaites* LA-1777. Validation with molecular markers linked to tomato leaf curl virus resistance revealed that LA-1777 carry*Ty2* and other putative resistant genes. Several high yielding dual purpose hybrids were also developed for fresh market and processing with high level of resistance to multiple diseases. Cherry tomato lines have also been bred for high TSS, total carotenoids, total phenols, flavonoids, vitamin C, acidity and lycopene content. IIHR-249-1, IIHR-2101 (*Solanum habrochaites* LA-1777), IIHR-2866 and IIHR-2864 recorded high values for quality parameters like total carotenoids, lycopene, vitamin C, total phenols, flavonoids and TSS. Drought tolerant root stock has been developed by an interspecific cross between *S. habrochaites* LA-1777 and *S. lycopersicum* (15 SB SB). Resistant sources have also been identified against *Tuta absoluta*, a serious insect pest reported from major tomato growing areas in the country in recent time. High temperature tolerant breeding lines are in pipe line.

Keywords: Begomovirus, Bacterial wilt, Early blight, Multiple disease resistance, Tomato breeding.

INTRODUCTION

Tomato is one of the important vegetable crops cultivated in tropical and sub-tropical regions of the world. In India tomato is cultivated in an area of 0.8 million (M) ha with a production of 22.33metric tons (MT). Due to its versatility in use and nutritive importance, consumption of tomato as fresh and in processed forms has created demand for the year round supply. As a result, its cultivation has become more intensive and also highly remunerative during scarcity. Both acidic and regular segment varieties and F_1 hybrids are commercially adopted by the tomato growers in the country. Tomatoes available during glut or harvested during *Rabi* (winter season) go for processing due to too low procurement prices which benefit the processors. Intensive and continuous cultivation of tomato in recent years has led to the prevalence of diseases and insect pests, which have become major production constraints in the country.

Begomoviruses, Groundnut Bud Necrosis Virus (GBNV), Bacterial Wilt (BW), root knot nematodes, foliar diseases such as Early Blight (EB), late blight and powdery mildew and insect pests such as red spider mites and leaf miner including pin worm (*Tuta absoluta*) have become major constraints of tomato production. The research efforts throughout the world by tomato research workers have resulted in the identification of stable resistance sources for several diseases except GBNV, Crinivirus and insect pests such as red spider mite and pin worm. Crop improvement programme has also resulted in the successful development of breeding lines, varieties and F_1 hybrids. Further, molecular markers linked to disease resistance have also been identified and successfully employed in MAB (Marker Assisted Breeding) for pyramiding and stacking of disease resistant genes into desirable genetic background. However, resistance to diseases has not been stable and durable over the seasons and locations due to the emergence of new pathotypes/ races/strains and G x E (Genotype X Environment) interaction. Fresh market tomatoes occupy more than 95% of the area under cultivation as tomatoes are consumed as fresh. In addition to high yield potential fruit quality attributes like fruit firmness, shelf life and distant transportability decide the commercial acceptance and adoption. Though the area under poly house, processing and cherry tomatoes is negligible, future research efforts need to be intensified to develop suitable varieties / F_1 hybrids. Keeping these in view research efforts were made at ICAR-IIHR in collaboration with other research institutions to address production challenges and to cater to the needs of tomato growers, consumers and processing industries in India.

Tomato Leaf Curl Disease (ToLCD), transmitted by white fly (*Bemisia tabaci*), is caused by *Begomoviruses* and is the most devastating disease on tomato causing considerable yield loss in major tomato growing areas of the country. Disease resistant varieties and hybrids are being commercially adopted to address this problem. However, prevalence of several *Begomovirus* strains (mono-partite and bi-partite) has been reported to breakdown ToLCV resistance in the commercially cultivated tomato varieties and hybrids. In order to address these problems, research was initiated at IIHR to develop stable and durable *Begomovirus* resistant genotypes with the following objectives:

- To screen all the available resistant genotypes to identify the stable source (s) to the most prevalent, Tomato Leaf Curl New Delhi Virus (ToLCNDV)
- Validation of molecular markers linked to Ty genes in resistant genotypes
- To pyramid Ty genes through Marker Assisted Selection (MAS) in to commercial varieties andhybrids
- Search for new sources of resistance to ToLCNDV.
- To develop new molecular markers linked to *Begomovirus* resistance

MATERIAL AND METHODS

1. Breeding for begomovirus resistance

1.1. Identification of stable sources of resistance against begomovirus and validation of molecular markers linked Begomovirus *resistance genes.*

A total of fifty-one genotypes with reported resistance to *Begomoviruses* were initially screened against mono-partite Tomato Leaf Curl Bangalore Virus (ToLCBV) by using viruliferous whitefly vector ab described by (Lapidot *et al*., 1997) in the screen house. Ten days old seedlings or two true leaf stage were inoculated with 10 viruliferous whiteflies. After 24 hours of virus acquisition the plants were shifted to glass house and retained at 25-32^{0}C in inoculation room.

Screening against Tomato Leaf Curl New Delhi Virus (ToLCNDV) was carried out through agro-inoculation according to (Prasanna *et al.,* 2014) concurrently at three locations *viz*., National Institute of Plant Genome Research (NIPGR), New Delhi, ICAR-Indian Agricultural Research Institute (IARI), New Delhi and ICAR-Indian Institute of Vegetable Research (IIVR), Varanasi.

Thirty-five genotypes were found to be resistant and all the 35 ToLCBV resistant genotypes were again screened against bi-partite *Begomovirus viz;* Tomato Leaf Curl New Delhi Virus (ToLCNDV) for which majority of commercial varieties and F_1 hybrids have been found to be susceptible. Symptom severity were assessed on 5 (0,1,2,3 and 4) scale as described by Lapidot *et al.*(1997).

Validation of molecular markers linked to different Ty resistance genes were done using linked markers. The markers validated in this study is mentioned in **Table 1.**

Table 1. Details of markers used in this study.

Gene	Marker Id	Sequence(5 ì-3 ì)	Reference
TY-1	JB-1	F-AACCATTATCCGGTTCACTC R-TTTCCATTCCTTGTTTCTCTCTG	Perez De Castro *et al*., 2007
Ty-2	PI16	F-CACACATATCCTCTATCCTATTAGCTG R-CGGAGCTGAATTGTATAAACACG	Yang *et al*., 2014
TY-3	SCAR1	F-GCTCAGCATCACCCTGAGACA R-TGCAGGAACAGAATGATAGAAAA	Dong *et al*., 2016 .
ty-5	TM273	F-GGTGCTCATGGATAGCTTAC R-CTATATAGGCGATAGCACCAC	Kadirvel *et al*., 2013

1.2 Identification of new molecular markers linked to Begomovirus resistance

To identify molecular markers linked to disease resistance, back cross inbred Lines (BIL's) mapping population has been developed by crossing resistant IIHR-2611 and susceptible parent 15 SB SB. An inter-specific hybrid has also been developed between 15 SB SB x IIHR-2809 (*S. peruvianum* L00671) through embryo rescue technique. Inter-specific F_1 failed to set fruit even on selfing and sibbing. However, back cross to *S. lycopersicum* (15 SB SB) was successful and back cross inbred Lines (BIL's) for molecular studies are being developed. These mapping population will be utilized for identification of new molecular markers linked to resistance gene.

1.3 Development of high yielding F_1 hybrids with resistance to ToLCNDV

Hybrid combinations carrying different Ty genes were developed using Line X Tester approach. Seven lines as a female and 9 Tester as male parents were crossed for hybrids development. Field test and horticultural performance of these hybrids along with parents and checks were evaluated at disease hot spots in concurrently three years. Additionally, a number of such F_1 hybrids were also screened against ToLCDNVat IARI, New Delhi, and found to be resistant to ToLCDNV, in addition to high yield potential and excellent fruit quality attributes.

1.4 Breeding for multiple disease resistant F_1 hybrids

Keeping in view, the need for development of multiple disease resistant varieties/hybrids breeding programme was initiated during 1995 at ICAR-IIHR, Bengaluru and the following triple resistant (ToLCV+BW+EB) lines were derived through backcross-pedigree method of breeding **(Figure 1).**

IIHR-2202

(Combined resistant to ToLCV + BW) x IIHR-1816

(Moderately resistant to EB)

↓

F1 x IIHR-1816

↓

BC1F1

(Triple resistant recombinants selected under artificial conditions and advanced)

↓

BC1F7

(Seven advanced breeding lines *viz;* TLBER-7-12-15-28, 7-12-15-29, 7-4-11-29, 7-4-11-34, 38-7-4-27, 38-7-41-43 and 12-21-43-1 with triple resistance were selected)

Fig. 1. Development of multiple disease resistance tomato advanced breeding lines.

1.5 Ground Nut Bud Necrosis Virus (GBNV)

Culture and maintenance of pure

GBNV infected tomato leaves were collected from infected plants in the field. The virus infections were identified primarily on the basis of rings symptoms on leaf and stem necrosis of infected plants and further confirmed by ELISA by using GBNV specific antibodies. The virus inoculum was prepared by using freshly harvested GBNV infected tomato leaves from the field. The infected tomato tissue (1 gm) was grounded in 5 ml 0.1 M sodium phosphate buffer (w/v), pH 6.5 supplemented with sodium sulphite (0.15%) and beta-mercaptaethanol (0.2%). The virus inoculum was filtered through cotton pad and a pinch of Celite was added. Finally, the virus inoculum was applied on the first true leaves about 6–7 days old healthy cowpea seedlings pre-dusted with carborundum powder. The inoculated plants were washed with tap water before drying the leaves and kept under shade in green house up to 7-8 days for symptom expression. After symptoms development, the virus was further inoculated on freshly raised cowpea seedlings and pure virus culture was maintained under insect proof glass house and used further for virus inoculation on tomato plants (unpublished).

Screening and selection of tomato plants resistance to Orthotospovirus

An attempt was made to transmit the virus on tomato and cowpea seedlings from infected tomato leaves, cowpea leaves and *N.benthamiana* leaves. Infected *N.benthamiana* was observed as the best source of virus inoculum. The virus infection was observed on inoculated Cowpea seedlings (100%) and tomato (90% - 95%) as compared to inoculum used from the leaves of tomato and cowpea. On the basis of results obtained, infected *N.benthamiana* leaves as an inoculum source was selected for further study. For screening of tomato lines inoculation was done by using freshly prepared inoculum from infected *N.benthamiana* leaves. Symptoms expression strats from 7 th day onwards in susceptible tomato lines and observations were recorded based on the presence and absence of virus and further confirmation was done by ELISA using GBNV specific antibodies.

1.6 Hybrids for protected cultivation

Indeterminate 6 F_1 hybrids with combined resistance to BW and ToLCV disease were developed for protected cultivation. These hybrids were evaluated for yield and BW resistance under protected conditions.

2. Breeding for abiotic stress tolerance

2.1 Root stock breeding for drought tolerance

An inter-specific F_1 hybrid has been developed between *S. habrochaites* LA-1777 and *S. lycopersicum* (15 SB SB) with moisture stress and drought tolerance, which can be used as a root stock. This has been successfully demonstrated using tomato hybrid Arka Rakshak as a scion variety.

Advanced breeding lines with high temperature tolerance and drought tolerance have been developed through SSD (Single Seed Descent) method.

3. Breeding for Fruit Quality Traits

3.1 Processing and cherry tomato lines

To cater the needs of processing industries, high yielding processing lines and F_1 hybrids with high lycopene and high TSS have also been developed. Cherry tomato breeding lines with high TSS, high lycopene and high beta-carotene have also been developed.

RESULTS AND DISCUSSION

Identification of stable sources of resistance against begomovirus and validation of molecular markers linked *Begomovirus* resistance genes.

Out of 35 genotypes tested for ToLCNDV,11 genotypes expressed resistant reaction against ToLCNDV upon agrofiltration. On validation of molecular markers linked to *Begomovirus* resistance revealed that two genotypes *viz.*, IIHR-2611 and IIHR-2809 did not amplify for any of the Ty markers, whereas the rest of the genotypes validated for different Ty marker (s) **(Table 2).** Two genotypes were found to carried both Ty2 and Ty3, and genotypes IIHR-2805 and IIHR-2896 carried Ty1 and Ty2 both. One genotype IIHR-2853 had Ty2, Ty3 and a recessive resistance gene ty5. These resistance lines are being utilized at ICAR-IIHR, for development of hybrids and cultivars.

Table 2. Tomato genotypes with resistance to ToLCNDV and molecular markers validation in ToLCNDV resistant genotypes

AccessionNo.	Pedigree	Source	Ty genes
IIHR-2101	*Solanum habrochaites* LA-1777	AVRDC, Taiwan	Ty-2 + Ty-3
IIHR-2611	TV-55-derivative of *S. lycopersicum* x *S. peruvianum*	ICAR-IIHR, Bengaluru	-
IIHR-2805	*S. peruvianum* L06138	AVRDC, Taiwan	Ty1+ Ty2
IIHR-2809	*S. peruvianum* L00671	AVRDC, Taiwan	-
IIHR -2852	CLN 3125P	AVRDC, Taiwan	Ty-1 + ty-5
IIHR -2853	CLN 3125A	AVRDC, Taiwan	Ty-2 + Ty-3 + ty-5
IIHR -2896	CLN 3552B	AVRDC, Taiwan	Ty-1 + Ty-2
IIHR -2901	CLN 3070J	AVRDC, Taiwan	Ty-2
IIHR -2902	CLN 3241-H 27	AVRDC, Taiwan	Ty-2+Ty3
IIHR -2917	ToLCVR 4F3 188-1-1	ICAR-IIHR, Bengaluru	Ty1
IIHR -2920	ToLCVR 4F3 38-1-1	ICAR-IIHR, Bengaluru	Ty1

Identification of new molecular markers linked to Begomovirus resistance

Back cross inbred Lines (BIL's) mapping population was developed by crossing resistant IIHR-2611 and susceptible parent 15 SB SB. An inter-specific hybrid has also been developed between 15 SB SB x IIHR-2809 (*S. peruvianum* L00671) through embryo rescue technique. These populations will be utilized for marker development linked to resistance genes.

In addition to, present study revealed that *S. habrochaites* cvLA-1777 was found to be resistant to bi-partite ToLCNDV and also validated for Ty2 and a similar allele of Ty3. Multiple sequence alignment of *S. habrochaites* LA-1777 was compared with IIHR-2902 for Ty3 locus both at the nucleotide level and protein level, which showed differences in both nucleotide and ammino acid level.

Among the ToLCNDV resistant genotypes, two genotypes *viz.,* IIHR-2611 and IIHR-2809 did not amplify for any of the Ty markers indicating new markers are linked to *Begomovirus*resistance. To identify molecular markers linked to disease resistance, mapping population has been developed between IIHR-2611 and susceptible parent 15 SB SB. An inter-specific hybrid has also been developed between 15 SB SB x IIHR-2809 (*S. peruvianum* L00671) through embryo rescue technique. Inter-specific F_1 failed to set fruit even on selfing and sibbing. However, back cross to *S. lycopersicum* (15 SB SB) was successful and back cross inbred lines (BIL's) for molecular studies are being developed.

High yielding F_1 hybrids with resistance to ToLCNDV.

Different hybrids carrying Ty genes were developed using advanced breeding lines for resistance to begomoviruses. Field test and horticultural performance of these hybrids along with parents and checks were evaluated at disease hot spots in consecutive three seasons. Additionally, a number of such F_1 hybrids were also found to be resistant to ToLCDNV, in spite of high yield potential and excellent fruit quality attributes. The performance of selected high yielding hybrids are given in **Tables 3 and 4.**

Hybrid Arka Rakshak and Arka Samrat yielded significantly higher than check Shakthiman and Lakshmi in all the three seasons. Arka Rakshak had given yield 63 % and 55% higher than two top yielding checks Lakshmi and Sakthiman respectively.

Three F_1 hybrids *viz;* H-502 (Lakshmi segment), H-504 (Shivam segment) and H-505 (FM hybrid) were developed by stacking Ty genes (Ty2+Ty3). All the hybrids were on par with commercial hybrids in yield but had more firm and large fruits with high level of resistance to ToLCV on artificial screening.

Table 3. Performance of promising tomato hybrids for yield over three seasons at ICAR-IIHR, Bengaluru

Sl. No.	Hybrids	Estimated yield (t/ha) for three seasons					
		DOP 21/4/09	DOP 15/12/09	DOP 17/3/10	Mean yield (t/ha)	% increase in yield over two top yielding checks	
		Summer-Kharif (2009)	*Rabi* (2009)	*Summer* (2010)		Lakshmi	Shakthiman
1	Arka Samrat	61.6	116.7	31.9	70.1	63	55
2	Arka Rakshak	62.7	78.2	34.2	58.4	36	29
3	H-169	34.8	71.0	15.4	40.4		
4	H-162	37.3	67.5	14.8	39.9		
5	H-248	50.4	81.2	28.3	53.3		
6	Arka Ananya	45.6	61.0	20.3	42.3		
7	Shakthiman	40.9	83.7	11.0	45.2		
8	Lakshmi	55.9	62.3	10.8	43.0		
9	Abhinava	35.7	69.0	11.4	38.7		
	CD@5%	15.2	30.6	6.0			
	CV%	18.6	20.4	15.5			

Seven advanced breeding lines *viz;* TLBER-7-12-15-28, 7-12-15-29, 7-4-11-29, 7-4-11-34, 38-7-4-27, 38-7-41-43 and 12-21-43-1 were selected with triple disease resistance against ToLCBV, Early Blight and Bacterial Wilt disease. These highly stable advanced breeding line were shown high yield and good horticultural performance in all the season with good firmness and deep red in colour. These advanced breeding lines carrying Ty2 gene were utilized for multiple disease resistance hybrids development.

Further two F_1 hybrids, *viz.,* Arka Samrat and Arka Rakshak **(Figure 2)** were developed with triple disease resistance to ToLCBV+BW+EB with high

Table 4. Response of tomato hybrids for tomato leaf curl Bangalore virus.

Sl. No.	Hybrids	45 DPI				
		Mean SSG[a]	DSI(%)	PDI	CI[b]	Host Reaction
1	H-502	0.33	6.68	33.33	8.33	R
2	H-505	0.25	5.01	25.00	6.25	R
3	Arka Rakshak	1.75	35.07	75.00	18.75	MR
4	Arka Samrat	2.08	41.75	80.00	40.00	S
5	Shivam	3.00	60.12	100.00	75.00	HS
6	Lakshmi	2.17	43.42	100.00	50.00	S
7	Punjab Chhuhara	4.00	80.16	100.00	100.00	HS

[a]Symptom severity grade (0-4); [b] CI calculated by scale as described by Kalloo and Benerjee, 1987.**Breeding for multiple disease resistant F_1 hybrids**

Arka Rakshak — Arka Samrat

Fig. 2. Field performance of triple disease resistant promising hybrids Arka Rakshak and Arka Samrat.

yield potential and good fruit quality attributes using these advanced breeding line.Reaction of tomato hybrids to ToLCD, bacterial wilt and early blight is presented in **Table 5**. However, resistance to *Begomovirus* was found to be inconsistent across locations and seasons due to the presence of only Ty2 gene deployed in male and female parents of both the hybrids and presence of different viral strains across the country. Several early blight tolerant lines were developed using NCEBR-1 as resistance source. Since the resistance level was moderate, *S. habrochaites* LA-1777 with high level of early blight tolerance has been used as donor parent to introgress EB resistant genes in to desirable genetic back ground. Marker assisted backcross breeding (MAB) has been successfully employed to pyramid *Begomovirus* resistance genes (Ty2+Ty3) and late blight resistance genes (Ph2+Ph3). *Begomovirus* resistant F_1 hybrids have also been developed in acidic types with very firm fruits on par with commercial hybrids.

Hybrids for protected cultivation

Indeterminate F_1 hybrids with combined resistance to BW and ToLCV diseasewere developed

Table 5. Reaction of tomato hybrids to ToLCD, bacterial wilt and early blight at IIHR, Bengaluru

Sl. No.		HybridsToLCV incidence (%)					Bacterial wilt incidence (%)					Early Blight incidence (PDI)			
		Kharuf 2009	Rabi 2009	Summer 2010	Kharif 2010	Mean	Kharif 2009	Rabi 2009	Summer 2010	Kharif 2010	Mean	Kharif 2009	Rabi 2009	Kharif 2010	Mean
1	Arka Samrat	0	0	30	14	11	0	0	10	0	2.5	39	16	28	28
2	Arka Rakshak	0	0	14	8	06	0	0	0	0	0.0	46	33	28	36
3	H-169	11	0	19	-	10	0	0	5	-	1.7		31		
4	H-162	8	0	32	16	14	0	0	16	0	4.0		32	40	36
5	H-248	0	0	12	20	08	0	0	3	0	0.8		31	41	36
6	A.Ananya	0	0	2	18	05	0	0	8	0	2.0	45	34	36	38
7	Shaktiman	0	0	15	-	04	13	21	58	-	30.7		41		
8	Lakshmi	0	0	5	18	06	10	17	61	0	22	80	34	56	57
9	Abhinava	8	0	0	37	11	18	16	50	2	21.5	69	61	55	62
10	Vybhav				39					0			41	32	
11	NS-501				23					0				44	
12	Pusa Ruby				97					0				80	
	CD@5%	2.03	0	9.8	10.0		3.99	11.12	11.8				9.62	3.69	

for protected cultivation. Hybrid PH-6321 exhibited highest yield and high TSS with high fruit firmness **(Figure 3).**

The average fruit weight was highest in hybrid PH-1025 (132.28 g), with highly firm fruits and deep red in colour. Performance to indeterminate hybrids is given in **Table 6.**

Fig. 3. Promising indeterminate hybrids under protected cultivation.

Table 6. Performance of promising indeterminate hybrids.

Sl. No.	Hybrids	Estimated yield /ha (t)	Average Fruit weight (g)	Pericarp Thickness (cm)	TSS (^{0}Brix)	Firmness (kg/cm^2)
1	PH-6321	92	120	0.65	4.1	7.5
2	PH-1025	89	127	0.70	5.1	7.2
3	PH-1021	88	130	0.60	4.7	8.7
4	H-501	79	94	0.70	5.0	7.7
5	H-503	73	146	0.7	4.7	10.5
6	H-506	98	113	0.90	4.1	6.7
	CV(%)	19.17	19.17	0.95	11.7	5.47
	C.D (P=0.05)	27.83	18.64	0.09	0.74	0.78

Ground Nut Bud Necrosis Virus (GBNV)

Screening work at ICAR-IIHR revealed that reported *Tospovirus* resistant tomato varieties *viz;* Pearl Harbour, Rey De losTempronos and Stevens (*Sw-5*) were found to be susceptible to prevailing local isolates of GBNV. Three lines *viz*; IIHR-2901 (CLN 3070J), IIHR-2953 (IPS made from F2 received AVRDC) & IIHR-2809 (*Solanum peruvianum*) were earlier found to possess GBNV resistance. All the three lines were artificially inoculated in order to confirm their resistance to GBNV. IIHR-2901 was highly resistant with 3% GBNV incidence, whereas IIHR-2953 & IIHR-2809 were moderately resistant with 13% & 20% GBNV incidence respectively **(Figure 4).**

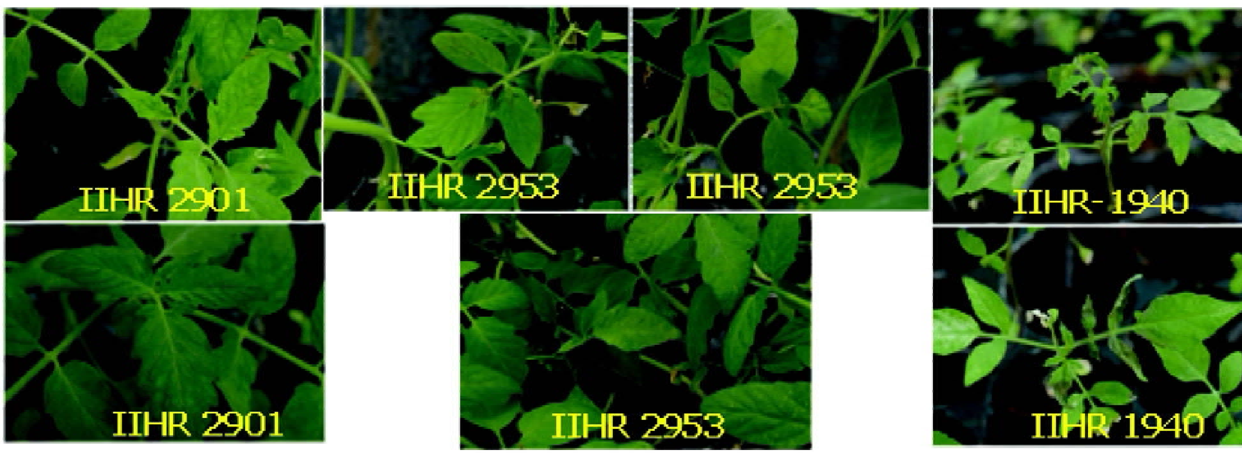
Identification of sources of resistance to South American tomato moth (*Tutaabsoluta*)

South American tomato moth (*Tuta absoluta*) has become a serious production constraint in major tomato growing areas of the country. This pest causes leaf damage by scrapping inter-veinal areas and also bore in to fruits with pinhole symptoms. Affected plants show severe defoliation and drying leading to reduction in crop yield and affected fruits become unmarketable. Since, chemical control of this pest is expensive and ineffective; host plant resistance seemed to be the most practical way to address this serious pest.

Twenty-one wild/cultivated/ advanced breeding lines (11 wild and 10 cultivated genotypes) of tomato were screened for resistance to *T. Absoluta* under field conditions (choice bioassay). Promising wild tomato accessions were evaluated further for their antibiosis activity (no choice bioassay) under laboratory conditions. Field bioassay revealed that, among 21 genotypes **(Figure 5)** screened, six wild accessions *viz.,Solanum pennellii* (LA 1940); *S. chilense* (LA1963); *S. arcarnum*(LA2157); *S. corneliomulleri* (LA1292); *S. lycopersicum* (LA1257) and *S. corneliomulleri* (LA1274) were found relatively

Reconfirmation of GBNVR in identified resistant tomato lines

IIHR No	Reaction
IIHR – 2901	HR (3%)
IIHR – 2953	MR (20%)
IIHR - 1940	MR (13%)



GBNVR sources identified in tomato

IIHR No	Reaction
IIHR – 2901	HR
IIHR – 2953	HR
IIHR - 1940	R (10%)

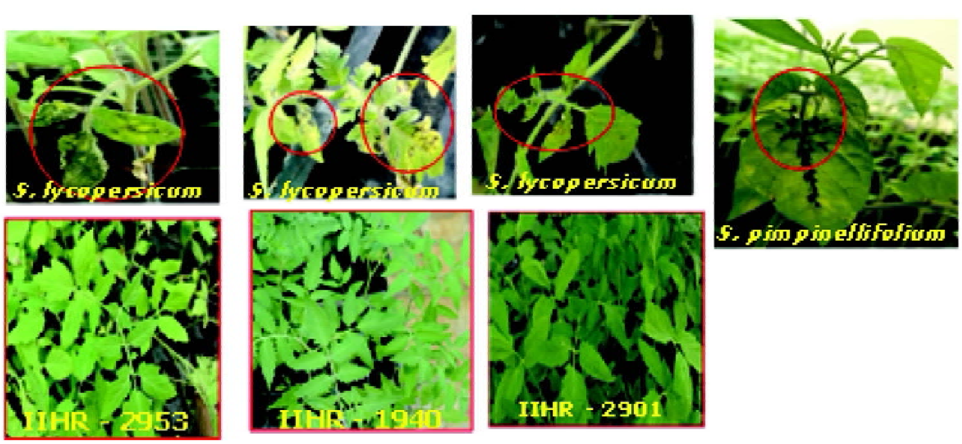


Fig. 4. Response of tomato lines against GBNV disease

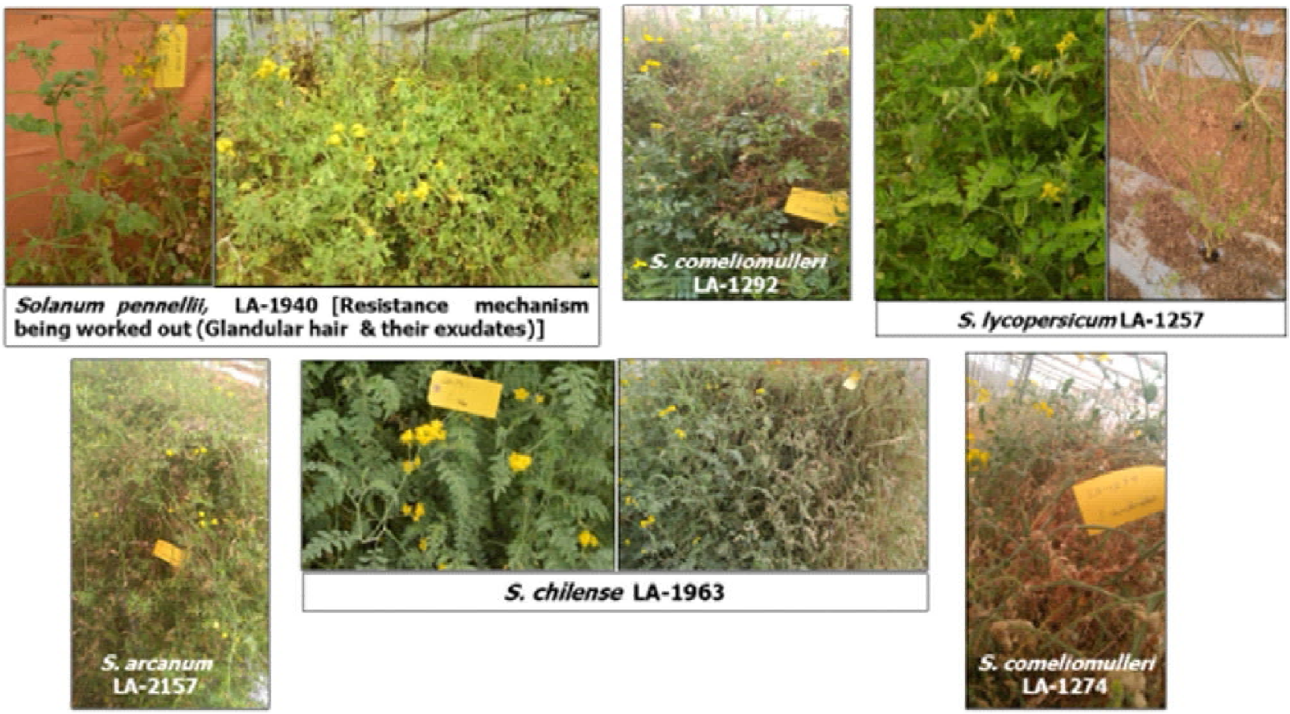


Fig. 5. Major resistance sources identified for *Tuta absoluta*

Fig. 6. Typical symptoms of *Tuta absoluta* on leaves and fruits in tomato.

resistant to *T.absoluta* based on mean per cent damage and remaining genotypes were either susceptible or highly susceptible to *T.absoluta* by recording relatively higher per cent leaf damage, mean larval number and adult activity. *In-vitro* studies further confirmed the promising wild accessions particularly S. *arcarnum* (LA2157); *Solanum pennellii* (LA 1940); and *S. coreliomulleri* (LA1292) as good source of resistance against *T. absoluta*. These genotypes recorded highest larval mortality, prolonged larval and pupal duration and reduced adult emergence of adults. Trichome density (glandular and non-glandular) based correlation studies were done for various parameters of pest damage. The number of glandular trichomes (Type I, IV, VII) showed negative correlation in different genotypes of tomato with reference to larval mortality **(Figure 6, Table 7)**

Interspecific hybridization between TLBER-38-7 x *S. pennellii* (LA-1940) was attempted and interspecific hybrids were obtained for incorporation of resistant genes in to cultivated background.

Root stock breeding for drought and heat tolerance

Drought is one of the most prevalent production constraint causing considerable losses in tomato production, inflicting economic as well as nutritional insecurity. Drought tolerance is a complex genetics and controlled by quantitative trait loci. Efforts have been made to identify QTLs tolerance to drought in tomato. Identification and development of drought tolerance root stocks is an non-genetical approach to enhance drought tolerance in tomato. Wild tomato, *S. habrochaites* alleles at QTL for traits associated with water-stress tolerance and the QTLs are located in chromosome 9 (Lounsbery *et al*., 2016).At ICAR-IIHR an inter-specific F_1 hybrid has been developed between *S. habrochaites* LA-1777 and *S. lycopersicum* (15 SB SB) with moisture stress and drought tolerance, which can be used as a root stock for drought tolerance. This has been successfully demonstrated using tomato hybrid Arka Rakshak as a scion variety. Advanced breeding lines with high temperature tolerance and drought tolerance have been developed through SSD (Single Seed Descent) method.

Table 7. Evaluation of tomato wild accessions against *Tutaabsoluta*

South American tomato moth, Tuta absoluta

Sl. No.	Varieties	Accession No.	Mean no of Larvae	Mean adult activity	Mean % Damage (Dec 2017)	Mean % Damage (Jan 2018)
1	S. pennellii	LA-1940	0.00	0.20	0.00	0
2	S.chilense	LA-1960	4.13	1.40	34.00	
		LA-1963	2.73	0.40	2.60	60
		LA-1967	4.13	1.80	99.00	
3	S. corneliomulleri	LA-1274	3. 80	1.40	24.00	60
		LA-1609	4.73	1.40	5.40	
		LA-1292	3.06	1.20	35.00	
4	S. lycopersicum	LA-1257	1.86	0.60	4.80	10
5	S. piminellifolium	LA-0397	7.00	3.40	99.6	
6	S. arcanum	LA-2157	4.26	1.00	18.00	20
7	S. peruvianum	LA-0455	5.00	1.60	100	

* S. pennellii (LA-1940) **is almost free from** Tuta absoluta **incidence followed by resistance in** S. chilense (LA-1963) **and** S. lycopersicum (LA-1257)

A total of 124 F_7plants derived from the cross involving large fruited HT line (CLN 3125A) and drought tolerant line (RF_4A) were raised for further advancement. Five IPS yielding higher than both the parents were selected for replicated yield trials. SH-1 an Inter-specific (15 SB SB x *Solanum habrochaites* LA-1777) was confirmed as drought tolerant root stock in tomato **(Figure 7).**

Breeding for processing

To meet the needs of processing industries, high yielding processing lines and F_1 hybrids with high lycopene and high TSS have also been developed. At ICAR-IIHR, Bengaluru, three promising hybrids for processing were developed with oblong to medium large fruit size weighing of 90- 100gm, and has deep red in colour. H-391 has joint less pedicel, high firmness (8.3 kg/cm^2) with high lycopene content of its puree (22.82mg/100g) is 50% more than Dabur's commercial

Fig. 7. RIL's advance for HT & DT SH-1 : Interspecific root stock & Shivam as Scion.

puree (13.95 mg/100g) makes this hybrid more suitable to processing industries. The detail of processing types hybrids is given in **Table 8 and Figure 8.**

Cherry tomato selections

Cherry tomatoes has become more popular all over the world because of a good source of vitamins

Table 8. Tomato hybrids evaluated for processing qualities

Hybrids	Fruit weight (g)	Length (cm)	Girth (cm)	Juice yield (%)	Pomace (%)	Green portion (%)	TSS (^{0}Brix)	Shape
H-391	75	5.88	5.25	69.57	23.42	6.28	6.12	Oval
H-423	96	6.32	5.55	65.73	25.74	12.60	5.94	Oval
H-502	101	5.91	5.45	74.25	13.90	16.96	5.32	Flat round
Abhinava	86	4.67	5.95	77.73	11.03	11.06	6.36	Oblong
Arka Rakshak	90	5.69	5.23	64.91	17.39	0.00	6.06	Oblong

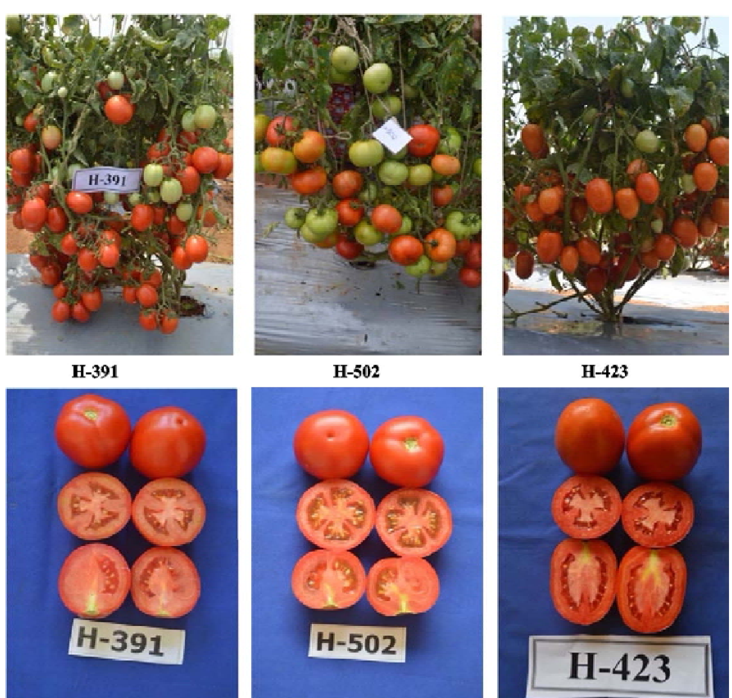


Fig. 8. Promising high yielding tomato hybrids suitable for processing.

A and C, solids content, good taste and fruit set even at high temperature (Prema *et al.*, 2011b). It is marketed at a premium to ordinary tomatoes. They also have good nutritional and antioxidant properties. The size of cherry tomatoes ranges from thumb tip to the size of a golf ball. And can range from being spherical to slightly oblong in shape (Renuka *et al*., 2014). The possible exploitation of hybrid vigour in cherry tomato has been taken up at few research centres however very little systematic attention has been paid by plant breeders to study performance for yield and its components in cherry tomato. Cherry lines received from AVRDC **(Figure 9)** were evaluated at ICAR-IIHR, Bengaluru for fruit qualities parameters **(Table 9).**

Doubling farmer's income through adoption of Arka Rakshak in farmers' field: A success story.

A survey was made on the adoption of Arka Rakshak by tomato growers in Karnataka during 2012 to 2014. Arka Rakshak recorded the highest yield of 190 t/ha (19kg/plant) by Mr. Chandrappa at Devasthanadahosalli, Chikkaballapura Taluk and District. Mr. Babu of Hennagara village, Bangalore urban district reported the highest net profit of Rs. 30 lakhs per hectare based on the total amount realized from 25000 plants raised on his 5acre plot. Fruits of Arka Rakshak were even exported to Bangladesh by Mr. Babu. Mr. Ramachandrappa from Kollegal taluk raised 65000 plants on his 12-hectare plot with an average yield of 84 tons/ha.

Table 9. Horticultural performance of selected cherry tomato lines.

Sl. No.	Tomato Accessions	T.S.S. (^{0}Brix)	% Acidity	Ascorbic acid (mg/100g)	Carotenoids (mg/100g)	Lycopene (mg/100gm)	Flavonoids (mg/100gm)	Total phenols (mg/100gm)	No. of locules/ fruit	Fruit firmness (kg/cm^2)	Pericarp thickness (mm)
1	IIHR-2754	7.2	0.6	22.2	10.9	6.5	9.8	74.3	2.3	4.4	2.2
2	IIHR-2858	6.8	0.4	35.6	9.0	4.4	13.6	59.7	3.0	5.0	2.4
3	IIHR-2860	6.5	0.5	35.1	7.8	4.8	11.3	78.8	2.3	4.2	3.9
4	IIHR-2863	6.5	0.5	38.7	15.0	7.0	11.5	76.2	2.7	4.5	2.4
5	IIHR-2864	7.7	0.3	29.5	3.3	0.8	9.1	50.8	2.3	7.2	4.8
6	IIHR-2865	4.7	0.5	23.0	2.7	0.7	11.3	56.8	3.7	5.0	2.2
7	IIHR-2866	7.0	0.3	29.9	5.7	1.0	6.0	51.0	2.3	4.6	4.0
8	IIHR-2876	6.8	0.3	25.5	11.9	7.1	8.4	77.0	2.3	5.8	2.8
9	Arka Ashish	3.7	0.3	13.7	16.6	7.8	3.1	22.8	3.3	8.2	7.4
	CD (P=0.01)	0.54	0.09	4.64	6.04	1.14	3.5	13.09	1.11	0.47	0.5
	CV (P=0.01)	1.96	1.79	0.8	9.32	2.13	6.35	3.8	4.38	0.84	2.14

Performance of Arka Rakshak from 2012 to 2014 revealed that, it recorded an average yield of 13.61 kg/plant (123 tons/ha.) with net earnings of Rs. 15.98 lakhs per hectare. Feedback from tomato growers revealed that Arka Rakshak was resistant to all the three diseases and recorded the highest yield with excellent fruit quality attributes such as very firm deep red fruits, and can withstand long distance transportability with good keeping quality of 15-20 days. The fruits of Arka Rakshak had been exported to Bangladesh because of its high self-life and preference to Bangladesh markets and it also responded well under precision farming practices **(Figure 10)**.

CONCLUSION

In conclusion, the development multiple disease resistance advance breeding lines/F_1 hybrid for dual purpose for fresh market and processing purpose have benefited to farmers by doubling their income through adoption of triple disease resistant hybrid Arka Rakshak. The development of cherry lines with high nutritive value with high lycopene and beta-carotene and vitamin

Fig. 9. Cherry lines with high β-carotene and lycopene content.

Fig. 10. Doubling farmer's income through adoption of triple disease resistant F_1-hybrid Arka Rakshak.

C can add to nutrition security. Individual plants carrying *Ty2/Ty2, Ty2/Ty3* and *Ty3/Ty3* have also been selected through MAS to study the contribution of individual gene in conferring begomovirus resistance. Efforts are in progress to develop hybrids possessing better tolerance toabiotic stresses compared to currently available hybrids. Resistance to tomato leaf curl disease was conditioned by *Ty2*in Arka Rakshak and Arka Samrat, which could give resistance to mono-partite begomo viruses but not to bi-partite begomo-viruses which are prevalent in major tomato growing areas of the country. Thus future prospects will be to pyramiding of Ty-3 gene in to desirable hybrid background can combat the bi-partite virus. Further challenges like GBNV and late blight disease can be addressed by pyramiding multiple of genes confirming resistance to these devastating diseases.

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