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Genetic improvement for yield, quality and leaf curl virus resistance in tomato (*Solanum lycopersicum* L.)

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Abstract
Five superior lines of tomato viz., VRSL-17, VRSL-18, VRSL-20, VRSL-22 and VRSL-40 were crossed with three testers viz., AVTO-1002, AVTO-1130 and AVTO-1314 which were resistant to tomato leaf curl virus in Line x Tester mating design. The resultant fifteen crosses along with eight parents and two checks i.e. US-618 and ArkaVikas were evaluated for yield, ToLCV resistance during late rabi, 2016. Highest fruit yield per plant was recorded in VRSL-22 x AVTO-1002 (3.17 kg) but was on par with VRSL-22 x AVTO-1314 (3.19 kg). With regard to disease reaction, one hybrid has shown highly resistant reaction, eight hybrids were resistant, four hybrids were moderately resistant and two hybrids have shown susceptible reaction under artificial screening. Among fifteen hybrids, no ToLCV incidence was recorded in VRSL-22 x AVTO-1002 (0.00), whereas VRSL-20 x AVTO-1002 and VRSL-22 x AVTO-1314 recorded 3.33% incidence of ToLCV under artificial screening. Combining ability analysis revealed that the magnitude of sca variance was greater than gca variance for the characters like number of primary branches per plant, days to 50 per cent flowering, number of clusters per plant, number of flowers per cluster, number of fruits per cluster, fruit set percentage, number of fruits per plant, days to first fruit harvest, fruit length, fruit diameter, number of locules per fruit, average fruit weight, fruit yield per plant, titrable acidity, ascorbic acid content, lycopene content and ToLCV incidence in field screening as well as artificial screening. This indicated the preponderance of non-additive gene action governing the inheritance of these characters. Hence, heterosis breeding is ideal to improve these traits.

Keywords: Tomato, ToLCV, Combining ability

Introduction
Tomato **(***Solanumlycopersicum*L., 2n=24, Family: Solanaceae**)** is a fruit vegetable originated in Peru Equador region of Latin America and was introduced by Portuguese merchants of East-India Company and became very popular vegetable in India. It is a popular and widely grown vegetable in the world after potato (FAOSTAT, 2015) [6] because of its wider adaptability, high yielding potential and suitability for variety of uses in fresh as well as processed food industries. In India, tomato is grown in an area of 0.882 million hectares with annual production of 18.74 million tonnes and productivity of 21.2 tonnes/ha. Andhra Pradesh (3.35 million tonnes) stands in first place in production followed by Karnataka (2.08 million tonnes), Madhya Pradesh (1.94 million tonnes), Telangana (1.48 million tonnes) and Odisha (1.39 million tonnes). In India average tomato productivity is low (21.2 t/ha) as compared to other countries like USA (88 t/ha), Spain (82.1 t/ha) and Brazil (60 t/ha) (NHB, 2015) [10]. Being a good source of minerals, acids, vitamins (A, B and C) and lycopene it has high nutritive value (Chadha, 2006) [5]. Lycopene is a carotenoid pigment, primarily responsible for the characteristic deep-red colour of ripe tomato fruits. The number of clinical evidences indicates the role of lycopene, as a natural antioxidant, in providing protection against a broad range of epithelial cancers (Yang *et al*. 2006) [12]. The scenario of tomato production in the country has tremendously changed over the past few decades with increasing popularity of hybrids. The growers, consumers and processing industries are with pressing demand to evolve high yielding hybrids with varying qualities as per local demands. Hence, it is imperative to obtain such hybrids which have high yielding potential along with good quality and resistance to pests and diseases.

Tomato is susceptible to many biotic factors such as pests and diseases. Among these, tomato leaf curl virus (ToLCV) disease transmitted by white fly (*Bemisiatabaci* Genn.) and caused bybegomovirus is a destructive disease of tomato in many parts of India (Muniyappa, 1991) [9]. Tomato cultivation, especially in autumn in North India and in summer in South India is adversely affected due to high incidence of tomato leaf curl virus disease and losses often exceeds 90 per cent (Butter and Rataul, 1981) [4].

Though hybrids/vareities tolerant to ToLCV were developed by several workers the resistance is getting broken down over a period of time. Hence, effort for identification of superior genotypes with resistance to diseases is a continuous process in any breeding programme. Keeping in view of this present investigation is taken up to identify best crosses with high yield potential coupled with disease resistance.

Materials and Methods

The experiment was conducted during late *Rabi*, 2016 at Horticultural Research Station, Dr. Y.S.R. Horticultural University, Venkataramannagudem, West Godavari District, Andhra Pradesh. This study involved five promising genotypes *viz*., VRSL-17, VRSL-18, VRSL-20, VRSL-22 and VRSL-40 which were crossed with three ToLCV resistant genotypes *viz*., AVTO-1002, AVTO-1130 and AVTO-1314 obtained from AVRDC, Taiwan in Line x Tester mating design. The resultant fifteen crosses along with eight parents and two checks i.e. US-618 and Arka Vikas were evaluated for yield, quality and ToLCV resistance. The experiment was laid out in Randomized Block Design with three replications. In each replication, F_1 hybrids and parents were grown on raised beds with drip irrigation and30 micron polythene mulch in paired rows at 120 x 50 x 50 cm spacing. In each replication, there were ten plants planted in two rows of 5 each. Observations were recorded on plant height, number of primary branches, days to 50 per cent flowering, number of flowers per cluster, number of fruits per cluster, number of fruits per plant, average fruit weight, yield per plant, number of locules per fruit, days to first fruit harvest, days to last harvest, total soluble solids, titrable acidity, ascorbic acid content, lycopene content and tomato leaf curl virus disease incidence.

Screening for tomato leaf curl (ToLCV) incidence

Tomato crosses were screened under natural epiphytotic conditions as well as challenged whitefly inoculation to select the resistant crosses for using in further breeding programme.

1. Field screening of tomato hybrids and lines against ToLCV

Tomato hybrids were screened for ToLCV resistance during late *rabi* season of 2016-17, when the natural ToLCV inoculum pressure was at its peak because of high white fly population during March and April months. Seedlings were raised in December first week in portrays and 21 day old seedlings were transplanted in the experimental plot during December last week. To increase the inoculums pressure, one row of ToLCV susceptible cv. ArkaVikas was planted after every 5th entry in the experimental plot. Disease incidence (% diseased plants) and symptom severity were recorded as detailed below.

2. Artificial screening of tomato leaf curl virus (ToLCV):

Whitefly *(Bemisiatabaci*Genn.) collected with the help of aspirator from the brinjal fields of Horticultural Research Station, Venkataramannagudem was maintained on brinjal, chrysanthemum and cotton plants grown in small plastic pots under insect proof screen house and were used for inoculation of ToLCV.Fifteen day old tomato seedlings grown in plug trays were transferred into insect proof screen house for inoculation.Mean while adult white flies collected from stock culture were allowed to feed on ToLCV infected twig for 24 hours of acquisition access period (AAP). Healthy tomato seedlings grown in plug trays at 2-4 leaf stage were kept in cage and viruliferous white flies were released into cage with the help of aspirator. White flies were allowed to feed on the test plants for 24 hours as inoculation access period (IAP). After IAP inoculated tomato seedlings were transferred to pots and kept in screen house for symptom expression.

Data on percentage of ToLCV incidence for fifteen hybrids along with hybrids and checks were recorded and presented as per the disease scale given by were Banerjee and Kalloo (1987) [3] (Table.1).

$$\text{ToLCV incidence (\%)} = \frac{\text{Total number of plants infected with ToLCV}}{\text{Total number of plants observed}} \times 100$$

Table 1: Disease scale for ToLCV as suggested by Banerjee and Kalloo (1987) [3]

Symptoms	Symptom severity grade	Response value	Coefficient of infection	Disease reaction
Symptoms absent	0	0.00	0-4	Highly resistant (HR)
Very mild curling leaves upto 25%	1	0.25	5-9	Resistant (R)
Curling, puckering of 26-50% leaves	2	0.50	10-19	Moderately resistant (MR)
Curling, puckering of 51-75% leaves	3	0.75	20-39	Moderately susceptible (MS)
Severe curling, puckering of > 75% leaves	4	1.00	40-69 70-100	Susceptible (S) Highly susceptible (HS)

The coefficient of infection was calculated by multiplying the% disease by the 'response value' assigned to each severity grade. Thus, the coefficient of infections combined the percentage of infection and its severity.

Results and Discussion

Perse performance of parents and hybrids

The mean performance of parents, hybrids and commercial checks for twenty-one characters are presented in the Table 2.Among hybrids the highest plant height was recorded in VRSL-22 x AVTO-1002 (110.30 cm) which was on par with VRSL-17 X AVTO-1002 (108.31 cm), VRSL-17 x AVTO-1130 (107.34 cm), VRSL-22 x AVTO-1314 (104.28 cm), VRSL-20 X AVTO-1002 (103.00 cm), VRSL-20 X AVTO-1314 (101.45 cm) and VRSL-22 X AVTO-1130 (97.03 cm). None of the crosses recorded significantly superior plant height over standard check US-618 (104.10 cm), whereas crosses VRSL-22 x AURO 1002, VRSL-17 x AVTO 1002, VRSL-17 x AVTO-1130, VRSL-22 x AVTO-1314, VRSL-20 x AVTO 1002 and VRSL-20 x AVTO-1314 recorded significantly superior plant height over susceptible check ArkaVikas (77.35cm). The cross, VRSL-18 x AVTO 1314 (7.20) recorded significantly higher number of primary

branches per plant which was on par with VRSL-22 x AVTO-1002 (6.97) and VRSL-18 x AVTO-1130 (6.60). The crosses, VRSL-18 x AVTO-1314 (7.20) and VRSL-22 x AVTO-1002 (6.97) recorded significantly more number of primary branches over ArkaVikas (6.00) and US-618 (5.93).Days to 50% flowering was lowest in VRSL-17 x AVTO-1130 and VRSL-22 x AVTO-1002 (30.33days), which was on par with VRSL-17 x AVTO-1314 (31.33 days), VRSL-20 x AVTO-1314 (31.33 days), VRSL-22 x AVTO-1314 (31.67 days), VRSL-40 x AVTO-1314 (31.67 days), VRSL-18 x AVTO-1130 (32.33 days) and VRSL-18 x AVTO-1314 (32.33 days). None of the crosses were significantly earlier to ArkaVikas (30.33 days) and US-618 (30.33 days).Among hybrids, highest number of clusters per plant was recorded by VRSL-22 x AVTO-1002 (53.53) which was on par with VRSL-22 x AVTO-1314 (50.80). None of the crosses recorded significantly higher number of flower clusters per plant than standard check US-618 (50.63), whereas VRSL-22 x AVTO-1001 (53.53) and VRSL-22 x AVTO-1314 (50.80) recorded significantly higher number of clusters per plant over susceptible check Arka Vikas (37.93).Among all the hybrids, VRSL-22 x AVTO-1002 (6.75) recorded more number of flowers per cluster, but was on par with VRSL-18 x AVTO-1130 (6.67), VRSL-20 x AVTO-1130 (6.58), VRSL-22 x AVTO-1314 (6.58), VRSL-40 x AVTO-1130 (6.58), VRSL-17 x AVTO-1130 (6.17) and VRSL-22 x AVTO-1130 (6.08).None of the crosses recorded significantly superior number of flowers per cluster compared to standard check US-618 (6.17), whereas all the crosses except VRSL-20 x AVTO-1314 (4.42) recorded significantly higher number of flowers per cluster over susceptible check, Arka Vikas (4.67).

Significantly higher number of fruits per cluster was recorded by VRSL-22 x AVTO-1002 (3.92) over all the other crosses and standard check US-618 (3.17), whereas all other hybrids are on par with US-618. The crosses VRSL-22 x AVTO-1002 (3.92), VRSL-18 x AVTO-1002 (3.17), VRSL-17 x AVTO-1314 (3.00), VRSL-20 x AVTO-1130 (3.00), VRSL-40 x AVTO-1002 (3.00), VRSL-40 x AVTO-1130 (2.92), VRSL-22 x AVTO-1314 (2.83), VRSL-17 x AVTO-1130 (2.75), VRSL-40 x AVTO-1314 (2.75) and VRSL-18 x AVTO-1314 (2.67) recorded significantly more number of fruits per cluster compared to ArkaVikas (2.08).Among all the hybrids VRSL-20 x AVTO-1314 recorded higher percentage of fruit set (58.50%) which was on par with VRSL-22 x AVTO-1002 (57.94%), VRSL-18 x AVTO-1002 (53.21%), VRSL-40 x AVTO-1314 (51.87%), VRSL-40 x AVTO-1002 (51.87%), VRSL-17 x AVTO-1314 (51.09%) and VRSL-18 x AVTO-1314 (46.08%). US-618 recorded a fruit set of 51.51% which was on par with all the other crosses, whereas VRSL-20 x AVTO-1314 (58.50%) and VRSL- 22 x AVTO-1002 (57.94%) recorded significantly superior percentage of fruit set compared to ArkaVikas (44.41%).

The cross VRSL-22 x AVTO-1314 recorded significantly highest number of fruits per plant (43.42) which was on par with VRSL-22 x AVTO-1002 (42.75), VRSL-40 x AVTO-1314 (41.94), VRSL-20 x AVTO-1314 (41.35), VRSL-20 x AVTO-1130 (41.00), VRSL-17 x AVTO-1002 (39.46) and VRSL-18 x AVTO-1314 (38.18). None of the crosses recorded higher number of fruits per plant over US-618 (48.98) but four crosses viz., VRSL-22 AVTO- 1314 (43.42), VRSL-22 x AVTO- 1002 (42.75), VRSL-40 x AVTO-1314 (41.94) and VRSL-20 x AVTO-1314 (41.35) were on par with US-618, whereas five crosses recorded significantly less number of fruits per plant compared to Arka Vikas (40.33) and remaining nine crosses were on par with Arka Vikas. The crosses, VRSL-17 x AVTO-1130 (66.00 days), VRSL-22 x AVTO-1002 (67.00 days), VRSL-17 x AVTO-1314 (67.33 days), VRSL-40 x AVTO-1130 (68.33 days) and VRSL-40 x AVTO-1314 (68.33 days) were on par with Arka Vikas and US-618 as far as days to first fruit harvest is concerned. The crosses, VRSL-22 x AVTO-1002 (128.33 days) and VRSL-17 x AVTO-1002 (126.67 days) were significantly superior to the standard check US-618 (121.00 days), whereas thirteen crosses were superior over Arka Vikas (112.00 days).

Among all the hybrids, VRSL-22 x AVTO-1002 recorded highest fruit length (5.97 cm) which was on par with VRSL-17 x AVTO-1130 (5.87 cm), VRSL-22 x AVTO-1130 (5.72 cm) and VRSL-40 x AVTO-1130 (5.69 cm). The best check US-618 recorded a fruit length of 5.73 cm which was on par with VRSL-22 x AVTO-1002 (5.97 cm), VRSL-17 x AVTO-1130 (5.87 cm), VRSL-22 x AVTO-1130 (5.72 cm), VRSL-40 x AVTO-1130 (5.69 cm), VRSL-40 x AVTO-1002 (5.35 cm) and VRSL-18 x AVTO-1002 (5.33 cm), whereas thirteen crosses recorded significantly higher fruit length compared to Arka Vikas (4.44 cm).Among the hybrids, VRSL-22 x AVTO-1002 (6.00 cm) recorded significantly higher fruit diameter but was on par with VRSL-22 x AVTO-1130 (5.92 cm), VRSL-20 x AVTO-1314 (5.88 cm), VRSL-40 x AVTO-1130 (5.82 cm), VRSL-18 x AVTO-1130 (5.81 cm), VRSL-20 x AVTO-1130 (5.76 cm), VRSL-20 x AVTO-1002 (5.72 cm), VRSL-40 x AVTO-1002 (5.68 cm), VRSL-17 x AVTO-1130 (5.65 cm) and VRSL-40 x AVTO-1314 (5.65 cm). Among checks, US-618 recorded a fruit diameter of 5.69 cm which was on par with all the crosses except VRSL-22 x AVTO-1314 (4.11 cm), VRSL-17 x AVTO-1002 (4.94 cm) and VRAL-18 x AVTO-1314 (5.12 cm). Arka Vikas recorded a fruit diameter of 4.74 cm which was on par with all the crosses except VRSL-22 x AVTO-1314 (4.11 cm) and VRSL-17 x AVTO-1002 (4.94 cm).Among hybrids, VRSL-17 x AVTO-1314 and VRSL-18 x AVTO-1002 (4.80) recorded highest number of locules per fruit followed by VRSL-20 x AVTO-1314 (4.00), while the least number of locules per fruit was recorded in VRSL-22 x AVTO-1130 (2.20). Fourteen hybrids recorded significantly more number of locules per fruit compared to superior check US-618 (3.00) and two crosses recorded significantly more number of locules per fruit compared to Arka Vikas (4.07).

Average fruit weight was significantly highest in VRSL-18 x AVTO-1002 (100.97 g) compared to all other crosses followed by VRSL-20 x AVTO-1002 (89.80 g).Three crosses viz., VRSL-18 x AVTO-1002 (100.97 g), VRSL-20 x AVTO-1002 (89.80 g) and VRSL-22 x AVTO-1002 (86.83 g) recorded significantly higher fruit weight compared to superior check US-618 (76.80 g), whereas seven crosses recorded significantly higher fruit weight compared to Arka Vikas (57.13 g). Significantly highest fruit yield per plant was recorded by VRSL-22 x AVTO-1002 (3.17 kg) but was on par with VRSL-22 x AVTO-1314 (3.19 kg), while the lowest fruit yield per plant was recorded with VRSL-18 x AVTO-1002 (1.92 kg). The crosses, VRSL-22 x AVTO-1002 (3.71 kg) and VRSL-22 x AVTO-1314 (3.19 kg) recorded significantly on par fruit yield per plant compared to superior check US-618 (3.75 kg), while VRSL-22 x AVTO-1002 (3.71 kg), VRSL-22 AVTO-1314 (3.19 kg), VRSL- 20 x AVTO-1130 (2.98 kg) and VRSL-20 x AVTO-1002 (2.95 kg) recorded significantly superior fruit yield per plant compared to Arka vikas (2.29 kg).

Among the hybrids, VRSL-40 x AVTO-1130 (5.39 ^{o}Brix) recorded significantly highest TSS and was on par with VRSL-18 x AVTO-1002 (5.25 ^{o}Brix), VRSL-17 x AVTO-

1130 (5.12 ^{0}Brix), VRSL-40 x AVTO- 1314 (4.96 ^{o}Brix), VRSL-17 x AVTO-1002 (4.90 ^{o}Brix), VRSL-20 x AVTO-1130 (4.87 ^{o}Brix) and VRSL-40 x AVTO-1002 (4.87 ^{o}Brix). The crosses, VRSL-40 x AVTO-1130 (5.39 ^{o}Brix), VRSL-18 x AVTO-1002 (5.25 ^{o}Brix) and VRSL-17 x AVTO-1130 (5.12 ^{o}Brix) recorded significantly higher TSS than superior check, US-618 (4.43 ^{o}Brix), whereas eleven crosses recorded significantly higher TSS than ArkaVikas (3.92 ^{o}Brix).Four crosses *viz.*, VRSL-18 AVTO-1314 (0.78%) VRSL-20 x AVTO-1002 (0.69%), VRSL-22 x AVTO-1002 (0.68%) and VRSL- 40 x AVTO- 1130 (0.67%) registered significantly on par titrable acidity with that of Arka Vikas (0.73%) and significantly higher titrable acidity compared to US-618 (0.57%).The hybrid VRSL-17 x AVTO-1002 (35.52 mg/100 g) recorded significantly highest ascorbic acid content but was on par with VRSL-17 x AVTO-1314 (34.59 mg/100 g), VRSL-20 x AVTO-1130 (34.47 mg/100 g), VRSL-18 x AVTO-1002 (34.34 mg/100 g), VRSL-20 x AVTO-1002 (33.10 mg/100 g) and VRSL-17 x AVTO-1130 (32.58 mg/100g). Twelve crosses recorded significantly higher ascorbic acid content over standard check US-618 (24.47 mg/100 g) and five crosses recorded significantly higher ascorbic acid content compared to Arka Vikas (28.93 mg/100 g).Among hybrids, the highest lycopene content was recorded with VRSL-40 x AVTO-1314 and VRSL-17 x AVTO-1314 (7.49 mg/100 g) which was on par with VRSL-22 x AVTO-1314 (7.26 mg/100 g), VRSL-20 x AVTO-1130 (7.15 mg/100 g) and VRSL-22 x AVTO-1002 (7.07 mg/100 g).Six crosses recorded significantly higher lycopene content compared to standard check US-618 (5.55 mg/100g) and seven crosses registered significantly higher lycopene content compared to Arka Vikas (5.18 mg/100g).

ToLCV incidence

Among hybrids ToLCV disease incidence ranged from 0 to 16.67% with an average of 4.22% under natural screening conditions (Table. 3). Among fifteen crosses four crosses (VRSL-22 x AVTO-1002, VRSL-22 x AVTO-1314, VRSL-40 x AVTO-1002 and VRSL-40 x AVTO-1314) recorded no ToLCV disease incidence, whereas VRSL-40 x AVTO-1130 (16.67%) recorded significantly highest ToLCV disease incidence. Four hybrids have shown highly resistant reaction and eleven hybrids recorded resistant reaction against tomato leaf curl virus (ToLCV) disease incidence under natural field screening. Among fifteen hybrids, no ToLCV incidence was recorded in VRSL-22 x AVTO-1002 (0.00), whereas VRSL-20 x AVTO-1002 and VRSL-22 x AVTO-1314 recorded 3.33% incidence of ToLCV and the highest ToLCV incidence was recorded in VRSL-17 x AVTO-1130 and VRSL-40 x AVTO-1130 (53.33%) in artificial screening conditions. With regard to disease reaction, one hybrid has shown highly resistant reaction, eight hybrids were resistant, four hybrids were moderately resistant and two hybrids have shown susceptible reaction under artificial screening (Table. 4). Similar findings in screening of tomato hybrids against tomato leaf curl virus (ToLCV) resistance were reported by Kumar *et al.* (2009) [7].

The choice of parents, in general is based on the general principle that the parents under selection should have a high *per se* performance for the desirable traits. Hence, the breeders are in absolute need of high or low mean values for desirable characters, which is considered as a main criterion for effective selection forever. If the relationship between combining ability effects and *per se* performance is established then it can at least help in rejecting large number of genotypes based on their *per se* performance for key characters in early segregating generations.

Combining ability variances and gene action

The estimates of general combining ability *(gca)* and specific combining ability *(sca)* variances, their ratios and gene action are presented in the Table. 5. General combining ability is generally associated with additive gene action, while specific combining ability is genetically due to dominance and epistasis. In the present study the results revealed that variances due to *sca* were higher in magnitude than the variances due to *gca* with a ratio of *gca* variance to *sca* variance ($\sigma^2 gca/\sigma^2 sca$) lower than unity(<1) for the characters number of primary branches per plant, days to 50% flowering, number of clusters per plant, number of flowers per cluster, number of fruits per cluster, fruitset (%), number of fruits per plant, days to first fruit harvest, fruit length, fruit diameter, number of locules per fruit, average fruit weight, fruit yield per plant, titrable acidity, ascorbic acid content, lycopene content and ToLCV incidence in field screening as well as artificial screening indicating the preponderance of non-additive gene action involved in the inheritance of genes. Hence, heterosis breeding and recombination breeding with postponement of selection to the later generations are ideal to improve these traits. Similar non-additive gene action for yield and yield attributing characters were reported in tomato by Mondal *et al.* (2009) [8], Alex Sandro *et al.* (2015) [1], Vipesh *et al.* (2015) [11] and Arun Kumar *et al.* (2016) [2].

The estimates of *gca* variances were higher than *sca* variances with the ratio of *gca* variance to *sca* variance more than unity for plant height, days to last harvest and total soluble solids, which indicates the preponderance of additive gene action involved in inheritance of these traits. Hence, direct selection by pure line selection or progeny selection or hybridization and selection with pedigree method could be employed to improve these traits.

Table 2: Mean performance of hybrids, parents and commercial checks for yield and quality characters in tomato.

S No	Character	Plant Height (cm)	Primary Branches/ Plant	Days to 50% Flowering	No of Clusters/ Plant	No of Flowers/ Cluster	No of Fruits/ Cluster	Fruit set (%)	No of Fruits/ Plant	Days to first harvest	Days to Last harvest	Fruit Length (cm)	Fruit Diameter (cm)	No of Locules/ Fruit	Average Fruit Weight (g)	Yield (Kg/ Plant)	TSS (° Brix)	Titrable Acidity (%)	Ascorbic Acid Content (mg/100 g)	Lycopene Content (mg/100 g)
Crosses																				
1	VRSL-17 x AVTO-1002	108.31	3.27	39.67	41.47	5.83	2.42	41.43	39.46	73.33	126.67	4.71	4.94	3.93	57.93	2.28	4.90	0.64	35.52	6.00
2	VRSL-17 x AVTO-1130	107.34	6.00	30.33	33.27	6.17	2.75	44.88	31.21	66.00	124.00	5.87	5.65	3.20	63.33	1.99	5.12	0.58	32.58	4.68
3	VRSL-17 x AVTO-1314	87.69	5.13	31.33	30.47	5.92	3.00	51.09	31.27	67.33	118.33	5.20	5.71	4.80	71.07	2.22	4.33	0.52	34.59	7.49
4	VRSL-18 x AVTO-1002	86.75	4.27	40.33	39.07	6.00	3.17	53.21	19.04	76.00	124.00	5.33	5.48	4.80	100.97	1.92	5.25	0.60	34.34	5.63
5	VRSL-18 x AVTO-1130	78.83	6.60	32.33	36.60	6.67	2.50	37.51	31.65	74.67	124.00	5.31	5.81	3.80	60.83	1.93	4.51	0.64	22.19	5.62
6	VRSL-18 x AVTO-1314	87.29	7.20	32.33	41.80	5.83	2.67	46.08	38.18	69.33	116.67	4.99	5.12	3.20	63.60	2.42	4.51	0.71	21.57	5.83
7	VRSL-20 x AVTO-1002	103.00	5.27	36.67	29.60	5.83	2.42	41.53	32.80	71.00	121.33	5.08	5.72	3.80	89.80	2.95	4.65	0.69	33.10	5.82
8	VRSL-20 x AVTO-1130	86.70	5.80	33.00	41.40	6.58	3.00	45.49	41.00	71.33	121.33	4.92	5.76	3.80	72.73	2.98	4.87	0.57	34.47	7.15
9	VRSL-20 x AVTO-1314	101.45	6.33	31.33	35.47	4.42	2.58	58.50	41.35	71.33	119.33	5.20	5.88	4.00	60.07	2.47	4.03	0.53	28.89	5.71
10	VRSL-22 x AVTO-1002	110.30	6.97	30.33	53.53	6.75	3.92	57.94	42.75	67.00	128.33	5.97	6.00	3.67	86.83	3.71	3.61	0.68	30.10	7.07
11	VRSL-22 x AVTO-1130	97.03	6.07	34.33	43.13	6.08	2.58	42.99	35.15	72.00	124.67	5.72	5.92	2.20	57.00	2.02	3.94	0.52	29.59	4.40
12	VRSL-22 x AVTO-1314	104.28	5.73	31.67	50.80	6.58	2.83	43.13	43.42	70.67	116.67	4.32	4.11	3.17	73.37	3.19	3.83	0.44	29.46	7.26
13	VRSL-40 x AVTO-1002	82.41	3.33	40.33	33.33	5.83	3.00	51.87	34.55	74.00	115.67	5.35	5.68	3.93	62.07	2.14	4.87	0.59	31.36	5.40
14	VRSL-40 x AVTO-1130	85.80	5.20	32.67	36.00	6.58	2.92	44.49	29.81	68.33	121.67	5.69	5.82	3.80	70.27	2.09	5.39	0.67	31.35	6.46
15	VRSL-40 x AVTO-1314	80.14	5.47	31.67	40.60	5.33	2.75	51.87	41.94	68.33	115.67	4.86	5.65	3.00	59.93	2.53	4.96	0.45	23.72	7.49
Lines																				
16	VRSL-17	99.87	3.67	32.00	42.87	5.58	2.67	47.92	46.85	67.00	116.67	5.16	4.10	3.00	60.07	2.81	5.44	0.36	24.35	3.68
17	VRSL-18	80.58	6.53	31.67	28.33	5.50	2.92	53.61	27.42	66.67	116.67	4.77	5.29	2.93	64.27	1.76	4.21	0.61	25.24	4.54

18	VRSL-20	70.19	5.53	34.67	29.67	4.42	2.33	53.06	35.29	67.00	119.67	5.44	4.24	3.73	66.60	2.35	4.41	0.56	24.20	6.13
19	VRSL-22	102.02	5.53	32.33	41.67	6.25	2.75	43.88	34.67	68.67	126.67	4.22	5.35	4.00	60.80	2.37	4.68	0.42	21.68	5.92
20	VRSL-40	83.16	4.90	34.33	35.00	5.67	2.67	46.84	34.71	74.00	124.00	5.03	5.24	3.20	54.80	1.92	3.95	0.37	22.64	5.69
Testers																				
21	AVTO-1002	111.33	3.33	43.00	31.73	4.50	1.67	37.04	19.51	76.33	116.67	7.20	5.15	2.00	107.70	2.11	4.74	0.61	22.49	5.89
22	AVTO-1130	114.28	4.33	34.00	25.20	5.75	1.92	33.21	20.92	67.67	116.67	6.87	6.28	4.93	103.73	2.17	4.41	0.43	26.18	4.97
23	AVTO-1314	101.23	4.07	33.67	30.73	4.33	1.83	42.59	26.20	76.33	125.00	5.77	5.18	3.07	77.67	2.04	4.42	0.34	18.16	6.50
Checks																				
24	ArkaVikas	77.35	6.00	30.33	37.93	4.67	2.08	44.43	40.33	66.33	112.00	4.44	4.74	4.07	57.13	2.29	3.92	0.73	28.93	5.18
25	US-618	104.10	5.93	30.33	50.63	6.17	3.17	51.51	48.98	66.67	121.00	5.73	5.69	3.00	76.80	3.75	4.43	0.57	24.47	5.55
	Grand Mean	94.06	5.30	33.79	37.61	5.73	2.66	46.64	34.74	70.29	120.53	5.33	5.38	3.56	71.17	2.42	4.54	0.55	27.65	5.84
	C.V.	13.92	7.94	4.09	8.93	7.20	14.58	16.39	13.85	2.31	2.24	4.56	4.11	2.43	6.94	15.15	7.41	8.76	8.20	7.06
	S.E.	8.43	0.24	0.80	1.94	0.24	0.22	4.41	2.78	0.94	1.56	0.14	0.13	0.05	2.85	0.21	0.19	0.03	1.31	0.24
	C.D. 5%	21.31	0.69	2.27	5.51	0.68	0.44	12.55	7.90	2.66	4.43	0.40	0.36	0.13	8.11	0.60	0.55	0.08	3.72	0.68
	C.D. 1%	29.12	0.92	3.03	7.35	0.90	0.65	16.75	10.54	3.55	5.91	0.53	0.48	0.18	10.82	0.80	0.74	0.11	4.96	0.90
	Range Lowest	70.19	3.27	30.33	25.20	4.33	1.67	33.21	19.04	66.00	112.00	4.22	4.10	2.00	54.80	1.76	3.61	0.34	18.16	3.68
	Range Highest	114.28	7.20	43.00	53.53	6.75	3.92	58.50	48.98	76.33	128.33	7.20	6.28	4.80	107.70	3.75	5.44	0.73	35.52	7.49

Table 3: Mean performance of hybrids, parents and commercial checks for tomato leaf curl virus incidence

S No	Character	ToLCV% (Field Screening)				ToLCV% (Artificial Screening)			
		Percent disease incidence	Arcsine transformed	Coefficient of infection	Disease reaction	Percent disease incidence	Arcsine transformed	Coefficient of infection	Disease reaction
Crosses									
1	VRSL-17 x AVTO-1002	3.33	10.51	1.67	R	10.00	18.43	7.50	R
2	VRSL-17 x AVTO-1130	10.00	18.43	7.50	R	53.33	46.91	39.00	S
3	VRSL-17 x AVTO-1314	6.67	14.97	6.67	R	26.67	31.09	13.34	MR
4	VRSL-18 x AVTO-1002	3.33	10.51	1.67	R	6.67	14.97	5.00	R
5	VRSL-18 x AVTO-1130	6.67	14.97	5.00	R	16.67	24.10	12.50	MR
6	VRSL-18 x AVTO-1314	3.33	10.51	1.67	R	6.67	14.97	5.00	R
7	VRSL-20 x AVTO-1002	3.33	10.51	1.67	R	3.33	10.51	1.67	R
8	VRSL-20 x AVTO-1130	3.33	10.51	1.67	R	6.67	14.97	5.00	R
9	VRSL-20 x AVTO-1314	3.33	10.51	1.67	R	26.67	31.09	13.34	MR
10	VRSL-22 x AVTO-1002	0.00	0.00	0.00	HR	0.00	0.00	0.00	HR
11	VRSL-22 x AVTO-1130	3.33	10.51	1.67	R	6.67	14.97	5.00	R
12	VRSL-22 x AVTO-1314	0.00	0.00	0.00	HR	3.33	10.51	1.67	R
13	VRSL-40 x AVTO-1002	0.00	0.00	0.00	HR	26.67	31.09	13.34	MR
14	VRSL-40 x AVTO-1130	16.67	24.10	8.34	R	53.33	46.91	40.00	S
15	VRSL-40 x AVTO-1314	0.00	0.00	0.00	HR	6.67	14.97	5.00	R
Mean		4.22	9.36	2.61		16.89	21.90	11.09	-
Lines									
16	VRSL-17	6.67	14.97	5.00	R	10.00	18.43	7.50	R
17	VRSL-18	16.67	24.10	8.34	R	53.33	46.91	40.00	S
18	VRSL-20	16.67	24.10	8.34	R	26.67	31.09	13.34	MR

19	VRSL-22	0.00	0.00	0.00	HR	6.67	14.97	5.00	R
20	VRSL-40	16.67	24.10	8.34	R	53.33	46.91	40.00	S
Mean		11.33	17.45	6.00		30.00	31.66	21.17	-
Testers									
21	AVTO-1002	0.00	0.00	0.00	HR	0.00	0.00	0.00	HR
22	AVTO-1130	0.00	0.00	0.00	HR	3.33	10.51	1.67	R
23	AVTO-1314	0.00	0.00	0.00	HR	3.33	10.51	1.67	R
Mean		0.00	0.00	0.00	-	2.22	7.01	1.11	-
Checks									
24	ArkaVikas	36.67	37.27	27.50	MS	76.67	61.12	76.67	S
25	US-618	0.00	0.00	0.00	HR	0.00	0.00	0.00	HR
Grand Mean		6.26	10.59	3.63	-	19.47	17.96	14.09	-
	C.V.	89.84	50.50	51.21	-	50.86	71.24	54.42	-
	S.E.	3.47	4.65	3.15	-	3.64	4.21	3.48	-
	C.D. 5%	6.86	9.21	6.40	-	8.35	11.17	10.23	-
	C.D. 1%	10.45	13.62	10.21	-	10.81	15.02	14.08	-
	Range Lowest	0.00	0.00	0.00	-	0.00	0.00	0.00	-
	Range Highest	16.67	28.88	27.50	-	36.67	37.21	76.67	-

HR : Highly Resistant R : Resistant MR : Moderately resistant
MS : Moderately susceptible S : Susceptible HS : Highly susceptible

Table 4: Response of tomato hybrids and parents for To LCV incidence under artificial screening

S. No	Reaction/Per cent infection	Number of genotypes	Hybrids, Parents and Checks
1.	Highly Resistant (HR) (Symptoms absent)	3	VRSL-22 x AVTO-1002, AVTO-1002, US-618
2.	Resistant (R) (Very mild curling of leaves upto 25%)	12	VRSL-17 x AVTO-1002, VRSL-18 x AVTO-1002, VRSL-18 x AVTO-1314, VRSL-20 x AVTO-1002, VRSL-20 x AVTO-1130, VRSL-22 x AVTO-1130, VRSL-22 x AVTO-1314, VRSL-40 x AVTO-1314, VRSL-17, VRSL-22, AVTO-1130, AVTO-1314
3.	Moderately Resistant (MR) (Curling, puckering of 26-50% leaves)	5	VRSL-17 x AVTO-1314, VRSL-18 x AVTO-1130, VRSL-20 x AVTO-1314, VRSL-40 x AVTO-1002, VRSl-20
4.	Moderately Susceptible (MS) (Curlin, puckering of 51-75% leaves)	0	--
5.	Susceptible (S) and Highly Susceptible (HS) (Severe curling, puckering of > 75% leaves)	5	VRSL-17 x AVTO-1130, VRSL-40 x AVTO-1130, VRSL-18, VRSL-40, ArkaVikas

Table 5: Estimates of general and specific combining ability variances and proportionate gene action for yield, yield attributes and quality characters in tomato

S.No	Characters	$\sigma^2 gca$	$\sigma^2 sca$	$\sigma^2 gca / \sigma^2 sca$
1	Plant height (cm)	0.0031	0.0006	1.55
2	Number of primary branches/ plant	0.36	0.80	0.45
3	Days to 50% flowering	4.58	7.57	0.61
4	Number of clusters/plant	6.27	24.31	0.26
5	Number of flowers / cluster	0.07	0.23	0.30
6	Number of fruits / cluster	0.02	0.13	0.15
7	Fruit set (%)	5.14	25.26	0.20
8	Number of fruits/plant	11.08	30.36	0.36
9	Days to first harvest	2.15	7.76	0.28
10	Days to last harvest	8.40	4.74	1.77
11	Fruit length (cm)	0.05	0.21	0.24
12	Fruit diameter (cm)	0.05	0.27	0.19
13	Number of locules per fruit	0.20	0.43	0.47
14	Average fruit weight (g)	51.82	161.75	0.32
15	Fruit yield per plant (kg)	0.08	0.14	0.57
16	TSS (ºBrix)	0.11	0.06	1.83
17	Titrable acidity (%)	0.002	0.006	0.33
18	Ascorbic acid content (mg/100 g)	7.55	10.09	0.75
19	Lycopene content (mg/100 g)	0.21	1.12	0.19
20	ToLCV incidence (%) field screening	2.36	12.60	0.19
21	ToLCV incidence (%) artificial screening	18.05	18.31	0.98

Conclusion

By considering the factors like *per se* performance, combining ability variances and gene action the crosses VRSL-22 x AVTO-1002 and VRSL-22 x AVTO-1314 were promising in terms of yield and resistance to ToLCV. These hybrids may be further tested in different locations for commercial exploitation.

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