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RESEARCH ARTICLE

Breeding tomatoes suitable for protected cultivation (Polyhouse) and confirmation of hybridity by SSR markers

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Abstract

In the present investigation on development of indeterminate high yielding hybrid/variety in tomato (*Solanum lycopersicum* L.) suitable for polyhouse cultivation, the study was carried out from June 2015 to May 2018. For this study, 51 tomato genotypes were collected from ICAR-NBPGR (Hyderabad), IIVR (Varanasi), IIHR (Bangalore) and from PAU (Ludhiana). These 51 tomato germplasm lines were evaluated for growth, yield and quality parameters across two different seasons. Based on performance, ten best performing accessions were selected and used as parents for hybrid development through Line x Tester analysis. From which, 21 hybrids were developed and evaluated for growth, yield and quality traits. Out of 21 hybrids, five promising hybrids were identified based on genetic analysis namely, EC160885 x EC 163605, Punjab Sartaj x EC163605, IHR2042 x EC163605, Punjab Sartaj x IIVR BT-10, IIHR2042 x IIVRBT-10. Their respective parents -- EC160885 (NBPGR, Hyderabad), Punjab Sartaj (PAU, Punjab), IIHR2042 (IIHR, BGL), EC163605 (NBPGR, Hyderabad) and IIVRBT-10 (IIVR, Varanasi) were also evaluated to confirm their potential. Among the hybrids Punjab Sartaj x EC163605, IIHR2042 x EC163605 and IIHR2042 x IIVR BT-10 were identified as best performing hybrids for growth, yield and quality parameters. The hybridity of these hybrids was confirmed through microsatellite markers (SSRs) which are highly suitable for accessing genetic purity and cultivar identification. These SSR markers revealed polymorphic bands between the parents and hybrids, thus confirming their genotypic purity as true hybrids. These promising hybrids may be recommended for large scale evaluation under polyhouse condition.

Keywords: genetic analysis; hybrids; markers; polyhouse; tomato

Introduction

Tomato, the second largest cultivated vegetable crop after potato, ranked seventh in the list of important crop species grown worldwide. Being a vegetable of multipurpose utility in food and processing industries, tomato was also a rich source of phytonutrients for human consumption. In addition to the local demand, tomato has also been identified as potential vegetable for export by the Agricultural and Processed Food Products Export Development Authority (APEDA) and was also very important in processing industry as it ranks first in processing vegetable crops in the world.

Protected cultivation also known as controlled environment agriculture (CEA) was highly productive, conservative of water and land and protective for the environment (1). Greenhouse, poly house and net house were suitable technology under the diverse climate for year-round and offseason vegetable production. Tomato was being extensively cultivated under protected conditions and gave higher returns. Cultivation of tomato under protected structure had distinct advantages in terms of earliness, higher productivity and quality produce which was free from pesticide residue and provided higher returns to farmers (2).

High yielding indeterminate tomatoes with long growing season were preferred for protected cultivation. Indeterminate types were characterized by continuous vegetative growth in which the terminal bud ended in leafy bud producing inflorescence at every third or more internodes and were best suited for protected cultivation owing to their long growing season. Therefore, an investigation was undertaken to produce indeterminate F_1 hybrids suitable for poly house cultivation with high yield and quality besides year-round production of tomato.

Materials and Methods

The present investigation was conducted during year 2015-2019 at Department of Vegetable Crops, Horticultural College and Research Institute, Tamil Nadu Agricultural University, Coimbatore. For this study, 51 tomato germplasm lines were collected from ICAR-NBPGR, Hyderabad, IIVR, Varanasi, IIHR Bangalore and from PAU, Ludhiana. These 51 tomato germplasm lines were evaluated the growth, yield and quality parameters for two different seasons.

Out of 51 germplasm lines best- performing ten accessions were selected and used as parents for hybrid development through Line x Tester analysis. The experimental material comprised of seven lines *viz.* Punjab Rakthak, EC 249515, EC 163683, EC 160885, Punjab Sartaj, IIHR 2042 and EC 521038 and three indeterminate testers *viz*. EC 163605, EC 163611 and IIVR BT-10. From these, 21 hybrids were developed (Table 1) and evaluated for growth, yield and quality parameters along with check hybrid 'Savannah' in randomized block design with three replications. The data recorded were statistically analysed using the suggested method (3).

Table 1. Details of hybrid combinations

SL. No	Hybrid combination (crosses)	Code No.
1	Punjab Rakthak × EC 163605	$L_1 \times T_1$
2	Punjab Rakthak × EC 163611	$L_1 \times T_2$
3	Punjab Rakthak × IIVR BT-10	$L_1 \times T_3$
4	EC 249515 × EC 163605	$L_2 \times T_1$
5	EC 249515 × EC 163611	$L_2 \times T_2$
6	EC 249515 × IIVR BT-10	$L_2 \times T_3$
7	EC 163683 × EC 163605	$L_3 \times T_1$
8	EC 163683 × EC 163611	$L_3 \times T_2$
9	EC 163683 × IIVR BT-10	$L_3 \times T_3$
10	EC 160885 × EC 163605	$L_4 \times T_1$
11	EC 160885 × EC 163611	$L_4 \times T_2$
12	EC 160885 × IIVR BT-10	$L_4 \times T_3$
13	Punjab Sartaj × EC 163605	$L_5 \times T_1$
14	Punjab Sartaj × EC 163611	$L_5 \times T_2$
15	Punjab Sartaj × IIVR BT-10	$L_5 \times T_3$
16	IIHR 2042 × EC 163605	$L_6 \times T_1$
17	IIHR 2042 × EC 163611	$L_6 \times T_2$
18	IIHR 2042 × IIVR BT-10	$L_6 \times T_3$
19	EC 521038 × EC 163605	$L_7 \times T_1$
20	EC 521038 × EC 163611	$L_7 \times T_2$
21	EC 521038 × IIVR BT-10	$L_7 \times T_3$

Results and Discussion

Mean performance of parents and crosses for growth, yield and fruit quality characters

The lines IIHR 2042 and Punjab Sartaj recorded high General Combining Ability (GCA) effects for seven traits *viz.* plant height, number of fruits per plant, individual fruit weight, yield per plant, harvest duration, fruit shape index, fruit firmness and shelf life. The tester EC 163605 was adjudged to be the good general combiner, as it showed significantly favourable GCA effect for the traits such as individual fruit weight, yield per plant, physiological loss in weight and shelf life and shows negative effects for days to 50 % flowering. The lines Punjab Sartaj, EC 160885, IIHR 2042 and the tester EC 163605 were highly suitable for further breeding programmes.

A total, 21 hybrids were generated and evaluated along with a check hybrid Savannah to assess their performance for yield potential under poly house condition. The hybrid EC 160885 × EC 163611 recorded high *per se* performance for eight traits *viz*. plant height, fruit firmness, pericarp thickness, number of locules per fruit, total soluble solids, ascorbic acid, acidity and lycopene content; IIHR 2042 × IIVR BT-10 and IIHR 2042 × EC 163605 for six traits *viz.* individual fruit weight, yield per plant, harvest duration and pericarp thickness; EC 160885 × IIVR BT-10 for six traits *viz.* individual fruit weight, fruit firmness, pericarp thickness, physiological loss in weight and ascorbic acid; Punjab Rakthak × EC 163611 for six traits viz. number of fruits per plant, fruit firmness, pericarp thickness, number of locules per fruit and physiological loss in weight; Punjab Sartaj × EC 163605 for five traits *viz*. number of flowers per truss, number of fruits per plant, individual fruit weight, yield per plant; Punjab Sartaj × IIVR BT-10 for five traits viz. yield per plant, fruit shape index, fruit firmness and pericarp thickness shelf life; EC 160885 × EC 163605 for five traits viz. individual fruit weight, pericarp thickness, physiological loss in weight, ascorbic acid and acidity. These were the hybrids which showed high *per se* performance for most of the traits whereas the cross EC 249515 × IIVR BT-10 and EC 163683 × EC 163605 which showed for plant height and pericarp thickness respectively. The evaluation of hybrids based on *per se* performance and Specific Combining Ability (SCA) effects, the hybrids IIHR 2042 × IIVR BT-10, Punjab Sartaj × EC 163605, Punjab Rakthak × EC 163611 and EC 160885 × EC 163611 showed good SCA effects. The hybrids suitable for recombination breeding were selected based on significant GCA effects of parents and non-significant SCA effects of the hybrids. Accordingly, IIHR 2042 × EC 163605 was found to be good for yield traits. Hence, these hybrids could be utilized for recombination breeding programme. Based on the magnitude and the number of traits, significant standard heterosis was observed in the hybrids *viz*. Punjab Sartaj × EC 163605, EC 160885 × EC 163611, EC 160885 × EC 163605 and EC 160885 × IIVR BT-10 and five promising hybrids were selected viz. Punjab Sartaj × EC 163605, IIHR 2042 × IIVR BT-10, Punjab Rakthak × EC 163611, EC 160885 × EC 163611 and Punjab Rakthak × IIVR BT-10 for the growth, yield and quality traits (Table 2).

Combining ability analysis and heterosis of parents and hybrids

The analysis of variance for combining ability showed that the existence of significant variation for fifteen characters, indicating a wide range of variability among the genotypes. The variance due to SCA was higher than that of GCA for all the characters indicating that the importance of non-additive gene action of inheritance for all the traits. Similar results in tomato had been reported in previous studies (4-6). GCA refers to the average performance of parents in a series of cross combinations and it was attributable to additive.

The lines IIHR 2042 and Punjab Sartaj recorded high GCA effects for seven traits *viz.* plant height, number of fruits per plant, individual fruit weight, yield per plant, harvest duration, fruit shape index, fruit firmness and shelf life, The tester EC 163605 was adjudged to be the good general combiner, as it showed significantly favourable GCA effect for the traits such as individual fruit weight, yield per plant, physiological loss in weight and shelf life and showed negative effects for days to 50 % flowering. The lines Punjab Sartaj, EC 160885, IIHR 2042 and the tester EC 163605 were highly suitable for further breeding programmes.

The evaluation of hybrids based on *per se* performance and SCA effects, the hybrids IIHR 2042 × IIVR BT-10, Punjab Sartaj × EC 163605, Punjab Rakthak × EC 163611 and EC 160885 × EC 163611 showed good SCA effects. The hybrids suitable for recombination breeding were selected based on significant GCA effects of parents and non-significant SCA effects of the

Table 2. Mean performance of parents and hybrids for growth, yield and quality traits

Parents and Hybrids	Plant height (cm)	Days to 50 % flowering	Number of flowers per truss	Number of fruits per cluster	Number of fruits per plant	Fruit weight (g)	Yield/ plant (kg)	Harvest Duration (days)
L_1- Punjab Rakthak	367.80	43.50	5.95	3.15	23.87	33.39	1.80	55.82
L_2- EC 249515	188.86	46.50	5.20	3.35	25.23	30.64	1.36	51.19
L_3- EC 163683	251.59	47.50	6.15	4.35	32.65	52.07	1.43	52.52
L_4- EC 160885	260.52	48.50	4.80	3.15	26.91	81.24	2.00	60.48
L_5- Punjab Sartaj	400.62	41.00	6.00	4.40	29.84	57.97	2.21	62.48
L_6- IIHR 2042	316.96	45.00	6.20	4.05	25.79	71.58	2.25	62.08
L_7- EC 521038	369.05	41.50	5.75	3.70	31.84	26.16	1.57	53.73
T_1- EC 163605	342.83	49.00	6.60	4.20	39.77	43.46	1.95	60.22
T_2- EC 163611	407.15	51.50	7.75	3.95	41.93	19.55	1.72	54.45
T_3- IIVR BT-10	400.82	41.50	5.20	4.25	38.12	45.83	2.03	63.37
Punjab Rakthak × EC 163605	363.69	38.00	6.60	4.35	36.49	43.68	2.10	64.29
Punjab Rakthak × EC 163611	244.44	41.00	7.30	4.50	45.41	41.00	1.93	59.85
Punjab Rakthak × IIVR BT-10	406.58	41.50	8.05	5.05	32.66	44.12	1.88	57.53
EC 249515 ×EC163605	339.53	41.00	7.45	5.10	38.81	52.14	2.44	60.25
EC 249515 × 163611	302.39	41.00	6.35	4.85	41.97	41.97	1.76	58.04
EC 249515 × IIVRBT-10	464.84	59.00	5.50	3.35	29.21	37.87	1.42	53.15
EC163683 x EC163605	268.94	41.00	6.05	4.65	36.11	47.67	2.11	60.76
EC163683 x EC163611	383.75	41.50	7.20	4.20	32.57	21.72	1.68	56.30
EC163683 x IIVR BT-10	358.89	45.00	6.80	4.70	32.74	41.11	1.86	59.59
EC160885 x EC163605	302.99	41.50	6.15	5.35	30.20	73.03	2.91	69.96
EC160885xEC163611	508.40	41.00	7.45	4.80	35.89	36.18	1.81	57.75
EC160885 x IIVR BT-10	352.80	51.00	4.95	3.00	21.21	72.87	2.02	62.42
Punjab Sartaj x EC163605	314.69	43.50	6.70	5.45	42.00	87.83	4.21	86.10
Punjab Sartaj x EC163611	378.00	50.00	6.05	4.90	36.49	51.98	1.97	61.01
Punjab Sartaj x IIVR BT-10	273.62	43.50	5.15	3.85	28.18	45.44	2.53	68.25
IIHR2042 x EC163605	380.22	38.50	6.10	4.15	39.45	62.49	2.99	72.07
IIHR2042 x 163611	418.85	43.50	5.95	4.50	48.33	35.30	1.67	55.12
IIHR2042 x IIVRBT-10	386.05	42.50	6.00	4.90	37.93	69.50	3.67	77.44
EC521038 x EC163605	362.57	37.00	5.65	4.00	29.09	41.60	1.85	57.09
EC521038x163611	361.53	46.50	6.15	4.05	35.80	32.28	1.55	52.31
EC521038xIIVR BT-10	341.75	38.00	6.40	3.40	28.53	22.99	1.95	60.75
Savannah (Check hybrid)	217.06	34.00	6.52	4.25	36.59	64.27	3.02	68.68
S.Ed	23.9370	2.631	0.681	0.367	2.281666	3.497142	0.154919	4.294764
C.D(0.5)	48.8198	4.901	1.620	1.261	4.653489	7.132467	0.31596	8.759229

hybrids. Accordingly, IIHR 2042 × EC 163605 was found to be good for yield traits. Hence, these hybrids could be utilized for recombination breeding programme. Based on the magnitude and the number of traits, significant standard heterosis was observed in the hybrids *viz.* Punjab Sartaj × EC 163605, EC 160885 × EC 163611, EC 160885 × EC 163605 and EC 160885 × IIVR BT-10 and five promising hybrids were selected *viz.* Punjab Sartaj × EC 163605, IIHR 2042 × IIVR BT-10, Punjab Rakthak × EC 163611, EC 160885 × EC 163611 and Punjab Rakthak × IIVR BT-10 for growth, yield and quality traits.

Each genotype, thus aided in selection of superior ones as parents for breeding programmes. Estimates of GCA effects indicated that the line Punjab Rakthak and EC 521038 recorded negative GCA effects for days to 50 % flowering (-2.48 and -2.14) and number of locules per fruit (-0.31 and -0.28) and positive GCA effect for number of fruits per plant (2.99) and ascorbic acid (1.40), lycopene (0.07) content respectively. The line EC 249515 showed positive and significant GCA effects for total soluble solids (0.48) and lycopene (0.14) content. EC 160885 showed positive GCA effects for plant height (30.23), individual fruit weight (12.94), ascorbic acid (6.37) and total soluble solids (0.58). The line Punjab Sartaj showed high GCA effects for individual fruit weight (14.00), shelf life (9.79), harvest duration (9.40) and yield per plant (0.70). IIHR 2042 showed positive GCA effects for plant height (37.21), individual fruit weight (8.01), shelf life (7.28), number of fruits per plant (6.71), harvest duration (5.83) and yield per plant (0.57). The tester EC 163605 presented positive GCA effects for individual fruit weight (10.60), shelf life (9.86), harvest duration (4.83) and yield per plant (0.45). The tester EC 163611 made positive for number of fruits per plant (4.30) and negative GCA effects for number of locules per fruit (-0.15). The tester IIVR BT-10 exhibited positive and significant GCA effects for ascorbic acid (0.89) content and total soluble solids (0.26). In this study, none of the parents was the best general combiner for all the traits, which corroborate with the earlier findings (7, 8). Thus, the lines IIHR2042, Punjab Sartaj and EC 160885 and tester EC 163605 were the most useful parents, as they were found good general combiners for growth, yield and quality attributes. The parents having high GCA effects were considered useful, since the GCA effect was due to additive gene action and was fixable (9). Hence, these parents may be recommended for exploitation in hybridization programme aimed at improving the yield components for which they were good general combiner. These results corroborated with the earlier studies in tomato (4).

The SCA reveals that the best cross combination among the genotypes which can be useful for developing hybrids with high vigour for various traits. The results revealed that there were no cross combinations consistently good for all the traits. In this study (Table 3), the cross Punjab Sartaj × EC 163605 showed significant SCA effects for seven traits *viz.* number of fruits per plant (5.62), individual fruit weight (15.49), yield per

Table 3. Estimates of specific combining ability (SCA) effect for growth, yield and fruit quality characters in tomato

Cross	Plant height (cm)	Number of fruits per cluster	Number of fruits per plant	Individual fruit weight	Yield per plant	Harvest Duration	Fruit shape index	Fruit firmness
$L_1 \times T_1$	50.05 **	-0.57	-2.53	-9.85 **	-0.33 **	-1.10	-0.11 *	0.34 **
L1 × T2	-107.01 **	-0.24	2.92	8.61 **	0.40 **	4.48	-0.05	0.42 **
L1 × T3	56.96 **	0.81 *	-0.40	1.24	-0.08	-3.38	0.15 **	-0.76 **
L2 × T1	-4.79	0.38	1.32	-2.45	0.11	-1.73	-0.04	-0.17
L2 × T2	-79.74 **	0.31	1.01	8.52 **	0.32 **	6.08	0.09 *	-0.31 **
L2 × T3	84.54 **	-0.69	-2.32	-6.07 *	-0.43 **	-4.35	-0.05	0.49 **
L3 × T1	-43.65 *	-0.15	1.48	0.24	-0.23	-2.96	-0.01	0.20
L3 × T2	33.34	-0.43	-5.54 **	-4.57	0.23	2.60	-0.00	-0.10
L3 × T3	10.31	0.58	4.06 *	4.33	-0.01	0.36	0.01	-0.10
L4 × T1	-60.47 **	0.68	0.27	1.74	0.21	1.75	-0.07	-0.30 **
L4× T2	107.12 **	0.31	2.49	-13.96 **	0.00	-0.44	0.09	-0.17
L4× T3	-46.65 *	-0.99 *	-2.76	12.23 **	-0.21	-1.31	-0.02	0.47 **
L5 × T1	17.19	0.43	5.62 **	15.49 **	0.85 **	9.48 **	-0.01	-0.48 **
L5 × T2	42.68 *	0.06	-3.36	0.78	-0.49 **	-5.60	0.03	0.08
L5× T3	-59.86 **	-0.49	-2.25	-16.26 **	-0.36 **	-3.89	-0.03	0.40 **
L6× T1	9.79	-0.65	-3.27	-3.87	-0.24 *	-0.97	0.08	0.35 **
L6× T2	10.59	-0.13	2.12	-9.91 **	-0.67 **	-7.91 *	-0.13 **	-0.25 *
L6× T3	-20.37	0.78	1.15	13.79 **	0.91 **	8.88 **	0.05	-0.10
L7× T1	31.89	-0.10	-2.88	-1.29	-0.38 **	-4.47	0.15 **	0.06
L7× T2	-6.97	0.12	0.36	10.54 **	0.20	0.78	-0.04	0.34 **
L7× T3	-24.92	-0.02	2.52	-9.25 **	0.18	3.68	-0.12 *	-0.40 **

plant (0.85), harvest duration (9.48), number of locules per fruit (-0.41), shelf life (5.54) and ascorbic acid (2.42). The cross EC 249515 × EC 163611 possessed significant SCA effects for six traits viz. individual fruit weight (8.52), yield per plant (0.32), shelf life (15.66), total soluble solids (1.05) and ascorbic acid (3.16). Likewise, the cross IIHR 2042 × IIVR BT-10 identified as good specific combiners for four traits *viz*. individual fruit weight (13.79), yield per plant (0.91), harvest duration (8.88) and shelf life (14.18) followed by Punjab Rakthak × EC 163611 and EC 163683 × IIVR BT-10. Remaining all other crosses had significant SCA effects except EC 163683 × EC 163605, EC 163683 × EC 163611 and EC 160885 × EC 163605. Previous research suggested that the crosses with high SCA effects could be much useful if they were accompanied by high GCA effects of parents involved (10).

In the present study, the parents involving the crosses Punjab Sartaj × EC 163605 (individual fruit weight, yield per plant and harvest duration) for the respective traits had high GCA effects and produced high SCA effects. The manifestation of high SCA effects by crosses where both the parents were good general combiners might be attributed to additive × additive gene action (11). The crosses having one parent with high GCA effects and other parent with low GCA effects were expected to throw desirable transgressive segregates if the additive genetic system present in high combiner and complementary epistatic effects act in same direction (12). The situation was well reflected in promising cross combinations having parents with high × low and low × high GCA effects also produced significant SCA effects as observed in the EC 160885 × EC 163611 (plant height), IIHR 2042 × IIVR BT-10 (yield per plant), EC 16085 × EC 163611 (number of locules per fruit and ascorbic acid) and EC 249515 × EC 163605 (lycopene content). These hybrids were the product of high x low and low x high GCA suggesting additive x dominant and dominant x additive type of gene interaction and hence could be used in heterosis breeding (13). The SCA effects of hybrids have been attributed to the combination of positive favourable genes from different parents or might be due to the presence of linkage in repulsion phase (14). Hence, selection of hybrids based on SCA effects would excel in their heterotic effect. It can be concluded that under polyhouse condition, the parents IIHR 2042, Punjab Sartaj, EC 160885 and EC 163605 can be utilized in multiple crossing programmes. The crosses, Punjab Sartaj × EC 163605, IIHR 2042 × IIVR BT-10 and Punjab Rakthak × EC 163611 had good SCA effects for most of the traits including yield per plant. For indeterminate growth habit, the cross EC 160885 × EC 163611 had good SCA effects. The selected parents having better performance can be crossed in the suitable combinations. The crosses which showed high SCA could be utilized in heterosis breeding.

Molecular tools were used to check the purity of the hybridity was confirmed through microsatellite markers (SSRs) which were found to be highly suitable for genetic purity assessment and cultivar identification using the SSR makers the hybrids were confirmed as true hybrids at the genotypic level through the polymorphic bands between the parents and hybrids. A total of 18 SSR primers (TES0715, TGS 0001, TGS 0017, TGS 0020 (Fig.1a), TGS 0025, TGS 0033 (Fig.1b), TGS 0042, TGS 0048 (Fig.1c), TGS 0051, TGS 0053, TGS 0056, TGS 0059 (Fig.1d), TGS 0061(Fig.1e), TGS 0064 (Fig.1f), TGS 0076, TGS 0080, TGS 0694 and TGS 0841) were selected from the linkage map of tomato genome for the amplification of genomic DNA. In this study, genetic purity and hybrid confirmation were accessed using these 18 SSR markers. Out of the 18 markers 14 were found to be polymorphic among the parental lines. The amplified product sizes ranged from 135 to 300 base pairs. From the selected 14 SSR markers, six were found to be polymorphic between male and female parents and these markers were used for screening the hybrid purity of five hybrids. The primers TGS001, TGS0017, TGS0080 and TGS0694 were found to be monomorphic from the parents screened (Table 4). Detection of genetic difference between the cultivars using molecular markers was found to be useful for identification and protection of variety for the plant breeder's intellectual property rights (15). SSR markers were highly suitable for the genetic purity assessment and cultivar identification due to their co-dominant inheritance, high polymorphism repeatability and reliability (16). The number of alleles detected per SSR markers varied from 1 to 3, with an

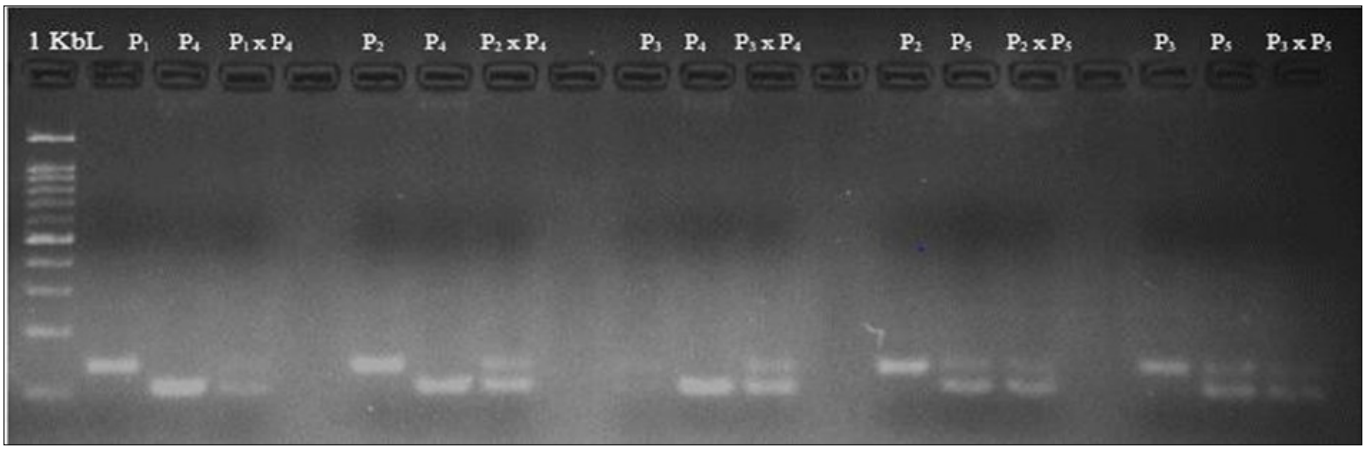

Fig. 1a. Primer TGS0020

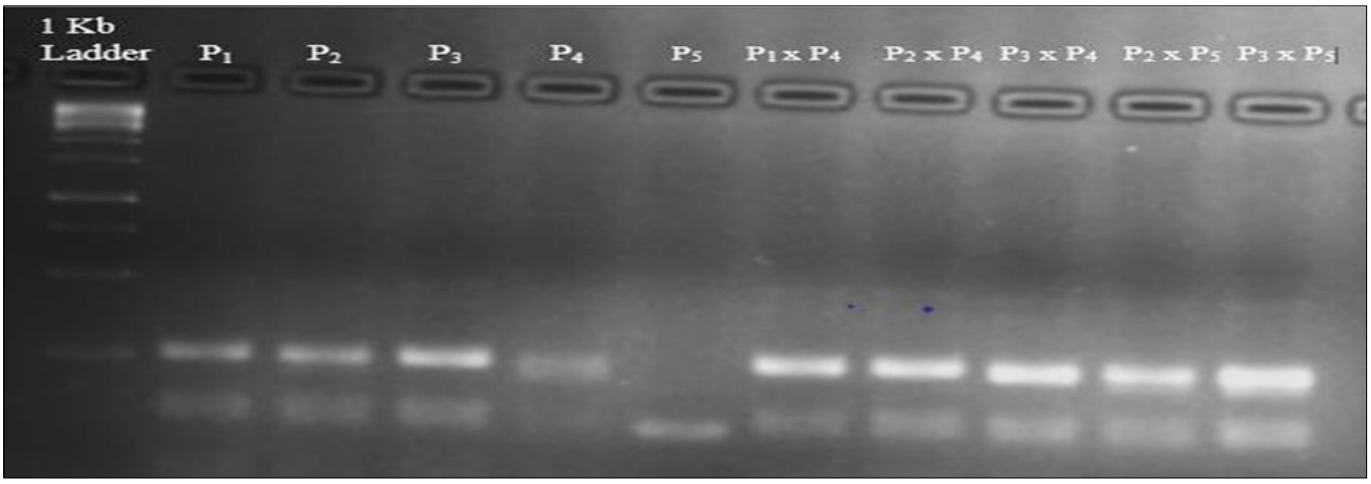

Fig. 1b. Primer TGS0033

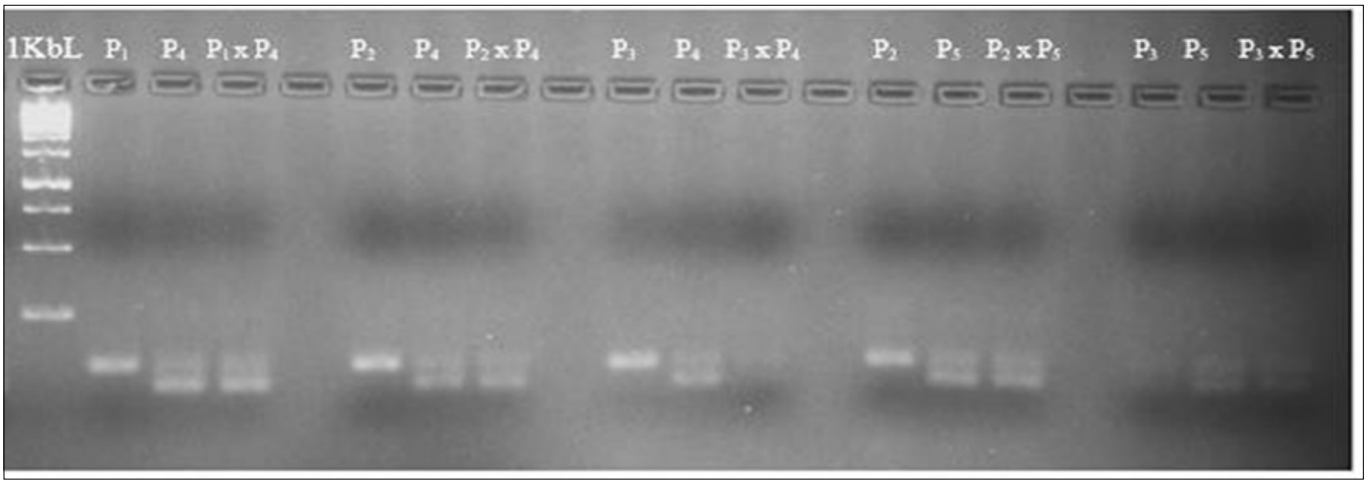

Fig. 1c. Primer TGS0048

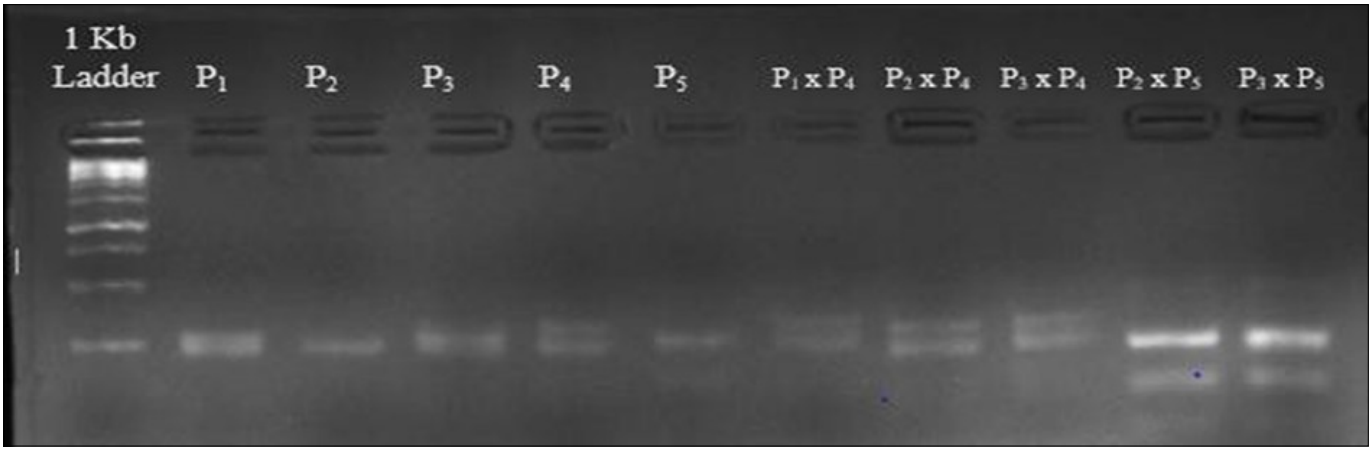

Fig. 1d. TGS0059

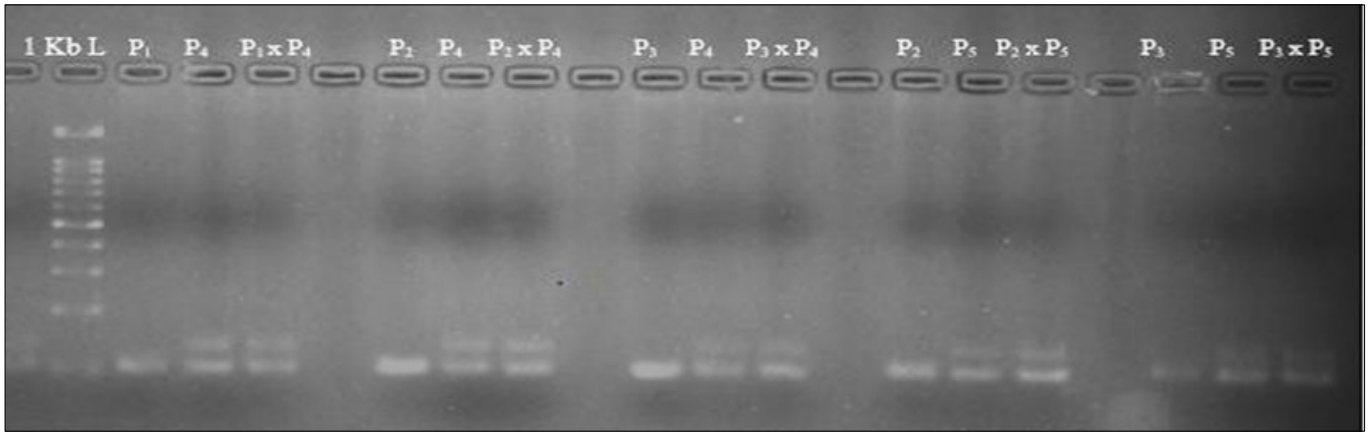

Fig. 1e. TGS0061

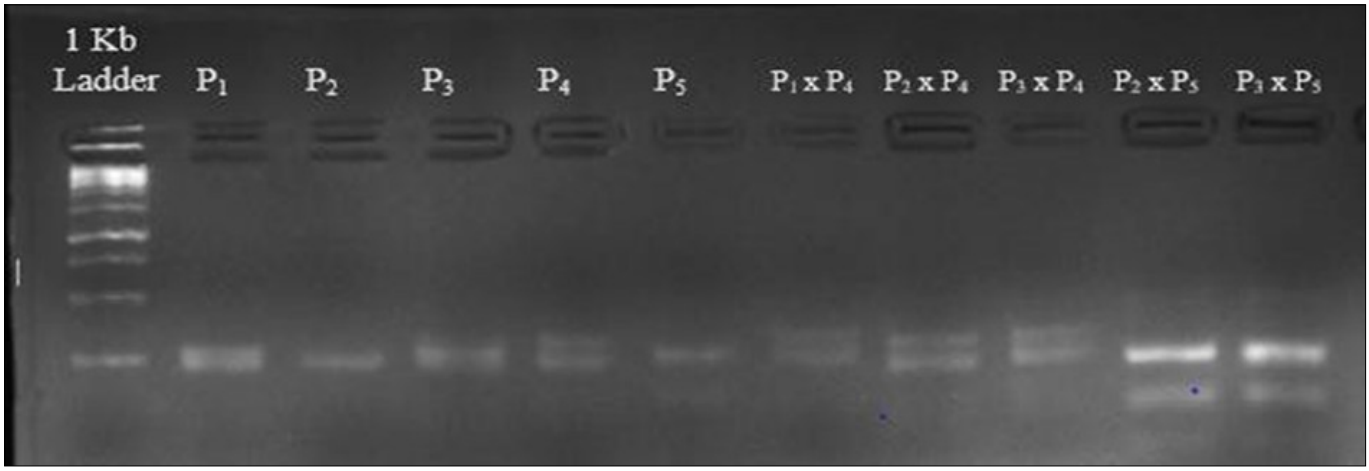

Fig. 1f. TGS0064

Fig. 1. Amplification profiling of parents and hybrids of Tomato by the primers.

Table 4. Parameters used for the evaluation of polymorphism in SSR markers

S. NO.	Primer	Sequence	Polymorphic Information Content (PIC)	Percentage of polymorphism
1	**TGS0061**	(Forward) GCACACCTTCATGGTTCGTTG (Reverse)TGACTTGCAAGCTAGTCTATTGTT	0.84	100
2	**TGS1841**	(Forward)GCGCTTCATCTCAACTCACGA (Reverse)TGAATAGCATGCTTGGCTTG	0.82	100
3	**TGS0020**	(Forward) TCTTTCAACTTCTCAACTTTGGC (Reverse)GCCGACTTCAAAAACTGCTC	0.77	100
4	**TGS0048**	(Forward)GTGAAGATCTCTTGTAAACGAACA (Reverse)CTTGGCACATGCATTTCATC	0.69	100
5	**TGS0059**	(Forward) CAAGATCCTTGGGGGTGTAA (Reverse)GTTTGAAGTTAGGGGCAGCA	0.69	100
6	**TGS0076**	(Forward) GCACACCTTCATGGTTCGTTG (Reverse)TGACTTGCAAGCTAGTCTATTGTT	0.67	100
7	**TGS0033**	(Forward) AGCAGCAGAAAATGGGCTTA (Reverse)GGAAATGAGCTAAAGGGAGAAA	0.65	100
8	**TGS0064**	(Forward) CAAGATCCTTGGGGGTGTAA (Reverse)GTTTGAAGTTAGGGGCAGCA	0.65	100
9	**TGS0053**	(Forward) GTTCCGACTCTGTTCCGTCTT (Reverse)AGCCGGGATGAAACATAAAA	0.63	100
10	**TES0715**	(Forward) TTATAGCCTTTCCGTACCGC (Reverse)GTTTCCAAATTGCATCCACC	0.63	100
11	**TGS0042**	(Forward) GAAGTTGGATGACCACCATCG (Reverse)TATCGGTCCAACCCATTTTC	0.52	100
12	**TGS0025**	(Forward) CCTTGATTTTGATTCCCCAA (Reverse)GAAGGTGCGTGATTTTGTGTT	0.52	100
13	**TGS0056**	(Forward) GGGGAGCACCCCTAGAAGTA (Reverse)TATGGGCTATGCCCAATTTT	0.36	100
14	**TGS0051**	(Forward) GTGAAGAGATGGGGTTGTGAA (Reverse)TCTGTTTTGAAGGGAAGAAGATG	0.33	100

average of 1.12 alleles per locus and average Polymorphic Information Content (PIC) values 0.63. The percentage of polymorphism, number of alleles and PIC value showed the level of genetic divergence among the genotypes. A PIC value greater than 0.5 was considered highly informative for genetic studies as previously reported (17,18). This method distinguished the hybrids from both male and female parents with more efficient and accurate manner. The results were like the findings of genetic purity assessment in tomato using SSR markers (15, 16, 19, 20).

Conclusion

The study successfully developed and evaluated high yielding indeterminate tomato hybrids suitable for poly house conditions. Among the 21 hybrids developed, three hybrids *viz.* Punjab Sartaj x EC163605, IIHR2042 x EC163605 and IIHR2042 x IIVR BT-10 were demonstrated superior performance in growth, yield and quality parameters. The genetic purity of these hybrids was confirmed using SSR markers, ensuring their reliability for commercial cultivation. These promising hybrids were recommended for further large-scale evaluations under poly house conditions to validate their performance and potential for adoption in protected cultivation systems.

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Authors' contributions

All the authors contributed equally to executing of the research idea, experimental design, provision of laboratory facilities for analysis, supervision of the study and interpretation of the data. They also jointly revised and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: The authors declare that they have no conflict of interest.

Ethical issues: None.

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