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Heterotic Pattern Involving Rin, Nor and Alc Alleles for Yield and Quality Traits in Tomato (*Solanum lycopersicum* L.)

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HIGHLIGHTS

- The heteroticpattern for yield and quality traits in tomato were assessed in two environmental conditions.
- Simultaneously, ripening genes i.e. rin, nor and alc genes were studied to prolong harvesting span.
- Out of 56 tomato hybrids, CLN1621L×alc-IIHR-2050 and LT-44×rin-Rutgers crosses were found best in main and spring season.

Abstract: An investigation on tomato was conducted at PAU, Ludhiana during 2020-21 with an objective of developing hybrids possessing maximum harvesting span with desirable horticultural traits. Experimental material, comprised of 56 F1 hybrids, 18 parental lines and standard check 'PTH-2', were transplanted in randomized complete block design in three replicates. Evaluation for all the experimental material was carried out during main as well as spring season. Cross combinations viz., PAU 114×nor-RM-1, PAU 2381×nor-RM-1 in main season while, crosses LT-44×rin-Rutgers, PAU 2381×rin-Rutgers in spring season recorded significant heterobeltosis and heterosis over check for yield and quality traits. Out of 56 hybrids, CLN1621L×alc-IIHR-2050, LT-44×rin-Rutgers in main as well as spring season, PAU 2381×nor-RM-1, Leader×nor-RM-1, LT-42×alc-IIHR-2050 and Roma×nor-RM-1 in main season and PAU 2381×rin-Rutgers, FL-556×rin-Rutgers, FL-556×alc-IIHR-2050 and LT-44×alc-IIHR-2050 in spring season were best for prolonged harvesting span vis-à-vis fruit yield, weight, minimum days from transplanting to first harvest, pericarp thickness, lycopene content, dry matter, TSS and titrable acidity. Therefore, the hybrid crosses which expressed higher yield potential in addition with acceptable qualitative performance together with maximum harvesting span could be utilized for commercial exploitation.

Keywords: Ripening mutant; combining ability; heterosis.

INTRODUCTION

Tomato (*Solanum lycopersicum* L.), belongs to the family Solanaceae. It is one of the most widely cultivated as well as consumed vegetable crop in the world due to its nutritive value, versatile uses, processability and identical flavour. Tomato referred as “Poor man’s orange” and “Protective Food” due to its special nutritive importance. It is a rich source of vitamin-A, vitamin-C, potassium, folate, minerals, lycopene, flavonoids, antioxidants and organic acids [1; 2]. Cultivated tomato is native of South America and it was introduced in India during the early 16th century by the Portuguese. It is well acclimatized under different climatic conditions due to its greater genetic variability and flowering behaviour. Therefore, leads to the development of infinite hybrids as well as open-pollinated varieties having special use and characteristics. In India, tomato is the leading processed vegetable and the third most important vegetable crop after potato and onion, while second in the world after potato. Tomato is used as raw in salad, sandwiches etc. and in processed forms like puree, sauce, chutney, soup, ketchup etc [3]. However, the postharvest shelf-life of tomato fruit is less due to its high perishable nature. To prolong postharvest availability, fruits are picked at the mature greenish stage but the quality of tomato is reduced as compared to those ripe on the plant itself [4]. If tomatoes are harvested in the full red ripe maturity stage, then fruits are marketable for four to six days under ambient room temperature [5; 6]. In the plains of north-western India, the main-season tomato crop raised from late November to early December and gives fruits for a short interval of time from late April to mid-May [7]. At many times the occurrence of heavy frost in December-January causing more loss in the main-season crop results in forcing growers to replant the crop in the late season. So, there is a need to develop tomato hybrids that delay ripening related processes and extend fruit availability up to the end of spring season.

A few ripening mutant alleles have been identified which interfere with the ripening related processes of tomato fruit which are slow ripening alcobaca (alc), non-ripening (nor), ripening inhibitor (rin), colourless non-ripening (Cnr), never ripe (Nr) and Green ripe (Gr) [8; 9; 10]. In heterozygous condition, these mutants extend the fruit availability period of tomato by delaying the ripening process also gives acceptable flavor and colour [11]. Mutant alleles shows reduced fruit deterioration process and resistance against post-harvest disease, which jointly resulted into excellent shelf life. Fruits from heterozygote plant for these mutants exhibit extended postharvest shelf-life by 250-500 per cent than other normal cultivars [12]. F1 hybrids containing these mutant alleles relatively takes more number of days from mature green to fully ripe stage as compared to the normal cultivars [13]. In north Indian parts, these mutant alleles shows extended fruit availability period by delaying ripening process of fruits on the plant [11; 14]. Heterozygous hybrids from these mutant alleles perform more uniformly in diverse environments as well as in stress condition than homozygous, this property discussed as a ‘physiological homeostasis’ [15]. Therefore, heterozygous F1 hybrids for these mutant alleles are a key solution to reduce the post-harvest losses and increase fruit availability period to a greater extent than other normal genotypes. Fruits from rin heterozygotes extended initiation of ripening and further proceeds very slowly as compared to normal cultivars [16]. Fruits softening also delayed when nor mutant appeared in heterozygous condition [17]. Studies by Mutschler [18] on alc and Kopeliovitch and coauthors [19] on rin and nor indicated the potential of exploiting mutant alleles in heterozygous condition to extend the availability period of tomatoes. Utilization and development of cultivars and lines by using rin, nor and alc with delayed ripening has been allowed in the traditional breeding [20]. So, our main goal of the research is production hybrid cross combinations of tomato which have extended maturity and good quality parameters acceptable by end-users through evaluation of hybrids.

METHOD AND MATERIALS

The present research programme was conducted at Vegetable Research Farm, Department of Vegetable Science, Punjab Agricultural University Ludhiana, India, during 2019-2020 and 2020-2021. The location of research field is 30° 55' north latitude, 75° 54' east longitude with an altitude of 247 m from mean sea level. Soil texture was sandy loam. The material for the current experiment consisted fourteen genetically diverse lines viz. SMZ-867, CLN 1621L, PAU 114, FL-556, PAU 2381, LT-44, Punjab Ratta, Roma, LT-42, LST-17, LST-6, Leader, Malintka and Spectrum. All lines were procured from PAU, Ludhiana except Roma, Leader, Malintka and Spectrum from USA and CLN 1621L from AVRDC, Taiwan. Four testers of ripening mutants viz. alc-IIHR-2050, nor-RM-1, rin-Rutgers and Olive Green (gene unidentified) (rin-Rutgers from USA, alc-IIHR-2050 from IIHR, Bengaluru, nor-RM-1 and Olive Green procured from PAU, Ludhiana); 56 F_1

hybrids and one standard check PTH-2 (Punjab Tomato Hybrid-2 from PAU, Ludhiana). The mean performance of parents and hybrids has been given in Table 2 and Table 3, respectively.

The fifty-six F1 cross breds were developed using line x tester mating design [21] by crossing between fourteen lines and four testers during February-March, 2020. The experimental material including 56 F_1 hybrids, 18 parental lines and one standard check 'PTH-2' had been sown in the well-developed nursery beds for raising seedlings on October 30, 2020 for main season (E_1) and on January 19, 2021 for spring season (E_2) crop. The transplanting in the experimental field was done on November 27, 2020 and March 1, 2021 for main (E_1) and spring (E_2) crop respectively with 3 replications in Randomized Complete Block Design. Each entry consisted 10 plants in every row in all three replications. All the agronomic and horticultural practices were followed in accordance with recommendations in the Package of Practice for Vegetable Crops [22]. The observations were recorded on pollen viability (%), days from transplanting to first harvest, harvesting span, average fruit weight (g), number of locules per fruit, pericarp thickness (mm), polar/equatorial diameter, total fruit yield (kg/plant), total soluble solids (Brix), dry matter (%), lycopene content (mg/100 g fresh weight) and titrable acidity (mg /100 ml of juice). Statistical analysis was performed through the OPSTAT program designed by Sheoran and coauthors [23].

RESULTS AND DISCUSSION

The Analysis of variance for the experimental design has shown that mean sum of square due to replications were found non-significant for all the traits except dry matter in both seasons, lycopene content in main (E_1) season and for harvesting span and TSS in spring (E_2) season (Table 1). This clearly indicated that the experimental plot was in heterogeneous in level of fertility. Highly significant differences between genotypes were noticed for all the traits except total fruit yield in spring (E_2) season. The significant mean square due to the lines, testers and line × tester clearly revealed the role of additive and non-additive gene effects for the inheritance of all the characters under study.

Heterosis over better parent and check was observed for all the studied traits. The top performing hybrids for all the traits has been given in Table 4. In main season, the cross PAU 114 × nor-RM-1 displayed promising heterosis (%) over better parent for days from transplanting to first harvest (-4.85%), harvesting span (10.13%), average fruit weight (16.57%), lesser locules number (-25.09%), pericarp thickness (15.71%), total fruit yield (16.16%) and TSS (11.69%). Another cross combination, PAU 2381 × nor-RM-1 was identified good over the better parent for pollen viability (36.53%), days from transplanting to first harvest (-4.10%), harvesting span (10.26%), locules number (-33.14%), pericarp thickness (7.15%), TSS content (13.68%) and lycopene content (29.08%). Under heterosis over checkPTH-2, the crosses Roma × nor-RM-1, PAU 2381 × nor-RM-1, PAU 114 × alc-IIHR-2050, Punjab Ratta × alc-IIHR-2050 and Leader × nor-RM-1 exhibited significant estimates for the most of the studied traits in main season. Similarly in spring season, cross combination SMZ-867 × Olive Green was found superior over better parent for lowest number of days from transplanting to first harvest (-12.87%), harvesting span (8.63%),average fruit weight (111.60%), lesser locules/ fruit (-29.58%), pericarp thickness (47.33%) and lycopene content (55.20%);and cross LT-44 × rin-Rutgers for days from transplanting to first harvest (-12.83%), harvesting span (8.22%), lesser locules (-16.91%), total fruit yield (53.08%) and dry matter content (21.83%). These results were in accordance with the findings of Kaushik and coauthors [24] who reported that the cross 102-13-6-1 × 2-1 exhibiting highly significant positive heterosis (63.12%) over standard check for total fruits yield/ plant. Khan and Jindal [25] identified that heterosis ranged from -6.49 % to -21.98 % over the better parent and -7.81% to -29.69% over check parent NS-524 in case of days to first harvest whereas Tamta and Singh [26] observed heterosis range of -3.41% to -8.19% over their better parent. Similarly, Salim and coauthors [27] found percent heterosis from -6.77 to 5.58% for harvesting duration over better parent. Karak and Hazra [28] also reported significant positive heterosis percentage over the better parent for average fruit weight in cross combinations namely, BCT-90 × 110 (42.96), BCT-109 × BCT-115 (42.07), BCT-90 × 109 (21.58), BCT-82 × 110 (15.66), BCT-50 × 132 (11.47) and BCT-53 × BCT-115 (8.96). Avdikos and coauthors [29] also reported the cross Elp-2 × Irn-1 exhibiting positive significant heterosis (10.00%) over the better parent for pericarp thickness. The crosses namely, SMZ-867 × nor-RM-1, LT-44 × alc-IIHR-2050, LST-6 × nor-RM-1, FL-556 × nor-RM-1 and FL-556 × alc-IIHR-2050 were identified as promising crosses for heterosis for most of characters over check PTH-2 in spring season. Garg and coauthors [30] also recorded standard heterosis for most of the traits which was 165.88 and 239.13% for yield, 102.28 and 195.96% for fruits number, 174.60 and 302.16% for marketable yield, -43.33 and -33.67% for firmness, 101.77 and 78.24% for average fruit weight, 71.51 and 126.47% for pericarp thickness, 70.61 and 33.84% for dry matter, 30.71 and 40.15% for lycopene, 40.98 and 45.10% for titrable acidity, 52.63 and 38.78% for TSS, 17.95 and8.04% for ascorbic acid content, 77.78 and 77.78% for shelf life in main and late season, respectively.

Out of fifty-six combinations, crosses namely, CLN1621L × alc-IIHR-2050, CLN1621L × Olive Green, CLN1621L × rin-Rutgers, PAU 114 × alc-IIHR-2050, FL-556 × alc-IIHR-2050, PAU 2381 × nor-RM-1, LT-44 × alc-IIHR-2050, LT-44 × rin-Rutgers, Punjab Rattta × alc-IIHR-2050, Punjab Ratta × nor-RM-1, Roma × alc-IIHR-2050, Roma × nor-RM-1, LT-42 × alc-IIHR-2050, LT-42 × Olive Green, LST-6 × rin-Rutgers, Leader × rin-Rutgers, Leader × nor-RM-1, Spectrum × alc-IIHR-2050, Spectrum × nor-RM-1 and Spectrum × rin-Rutgers were identified with maximum harvesting span in main (E_1) season. In spring (E_2) season crosses viz. SMZ-867 × nor-RM-1, SMZ-867 × Olive Green, CLN1621L × alc-IIHR-2050, CLN1621L × nor-RM-1, PAU 114 × rin-Rutgers, FL-556 × alc-IIHR-2050, FL-556 × rin-Rutgers, PAU 2381 × rin-Rutgers, LT-44 × alc-IIHR-2050, LT-44 × Olive Green, LT-44 × rin-Rutgers, Punjab Ratta × alc-IIHR-2050, LST-17 × Olive Green, LST-6 × nor-RM-1, Leader × nor-RM-1, Malintka × nor-RM-1, Malintka × Olive Green, Malintka × rin-Rutgers, Spectrum × Olive Green and Spectrum × rin-Rutgers were recorded with maximum harvesting duration.

Table 1. Analysis of variance for experimental design for different characters in main (E_1) and spring (E_2) season

Source of variation	d.f	Pollen Viability (%)		Days from Transplanting to the First Harvest		Harvesting Span (Days)		Average Fruit Weight (g)		Number of Locules per Fruit		Pericarp Thickness (mm)	
		E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Replications	2	14.25	28.82	8.07	6.54	4.43	32.46**	1.73	36.17	0.04	0.11	0.06	0.17
Parents	17	178.06**	388.95**	18.28*	37.74**	25.17**	21.86**	838.89**	1730.91**	0.68**	1.56**	6.61**	6.06*
Lines	13	131.86**	459.18**	16.23*	32.47**	28.11**	26.16**	710.26**	1526.11**	0.79**	1.99**	4.35**	4.42**
Testers	3	434.44**	108.00**	5.40	11.64	14.87**	9.26*	1497.90**	2161.47**	0.28**	0.11	15.94**	13.89**
Lines vs testers	1	9.52	318.88**	83.73**	184.42**	17.86*	3.80	534.23**	3101.56**	0.03	0.39*	8.22**	3.91**
Parents vs. hybrids	1	1875.65**	1182.76**	169.17**	305.91**	228.25**	137.37**	466.34**	2846.14**	1.57**	0.62**	2.32**	0.01
Hybrids	55	364.89**	293.02**	37.14**	22.52**	41.92**	39.84**	1199.20**	947.28**	0.88**	0.47**	4.97**	3.87**
Error	146	17.01	12.45	8.86	5.34	3.23	3.00	2.44	68.90	0.05	0.07	0.06	0.47

Source of variation	d.f	Polar/Equatorial (P/E) ratio		Total Fruit Yield (kg plant^{-1})		Total Soluble Solids ($^{\circ}$Brix)		Dry Matter (%)		Lycopene (mg/100 gm of fresh weight)		Titratable Acidity (mg /100 mL fruit juice)	
		E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Replications	2	0.00	0.00	0.01	0.28	0.08	2.59**	0.99**	2.11*	1.26*	0.16	0.00	0.02
Parents	17	0.42**	0.29**	0.67**	0.36	4.30**	0.82**	6.48**	1.40**	3.52**	1.82**	0.07**	0.05**
Lines	13	0.48**	0.31**	0.695**	0.23	5.36**	0.442**	6.74**	1.28**	0.69**	0.278	0.02	0.06**
Testers	3	0.26**	0.30**	0.77**	0.50*	1.00**	2.48**	7.40**	2.37**	4.44**	6.47**	0.09**	0.01
Lines vs testers	1	0.09**	0.02*	0.00	1.69**	0.42**	0.69*	0.31*	0.02	0.03	7.91**	0.01	0.04
Parents vs. hybrids	1	0.61**	0.56**	3.06**	4.79**	5.83**	0.08	0.06	0.21	15.70**	6.36**	0.07**	0.00
Hybrids	55	0.10**	0.07**	0.52**	0.26**	3.31**	0.77**	2.83**	2.11**	2.37**	0.67*	0.04**	0.03**
Error	146	0.00	0.00	0.03	0.15	0.04	0.16	0.07	0.56	0.27	0.42	0.01	0.02

*,** significant at 5% and 1% level, respectively

Table 2. Mean performance of parents and check for different characters in main (E_1) and spring (E_2) season

Parents	Pollen Viability (%)		Days from Transplanting to the First Harvest		Harvesting Span (Days)		Average Fruit Weight (g)		Number of Locules per Fruit		Pericarp Thickness (mm)	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Lines												
SMZ-867	70.00	60.27	140.00	70.73	36.07	36.27	20.60	21.20	2.00	2.00	4.25	3.93
CLN 1621L	81.67	91.53	138.07	72.47	36.27	30.93	55.45	51.66	2.50	3.73	4.15	4.19
PAU 114	85.40	56.13	138.80	73.13	31.40	33.00	76.32	77.90	2.00	2.07	6.00	6.84
FL-556	83.07	62.20	141.67	72.07	38.60	35.67	68.06	68.25	2.00	2.20	5.67	6.13
PAU 2381	72.40	76.67	136.67	71.60	39.00	40.07	78.85	74.60	3.50	2.07	5.38	6.34
LT-44	90.93	53.27	139.80	78.93	32.27	28.73	88.85	96.04	3.34	4.73	5.64	7.23
Punjab Ratta	79.93	57.27	140.73	66.00	36.60	38.07	78.53	70.68	2.17	2.07	7.06	6.61
Roma	80.40	75.67	138.67	72.53	31.47	34.73	68.86	50.89	2.67	2.07	5.37	4.68
LT-42	90.93	83.07	143.40	71.67	35.27	35.00	66.75	67.21	2.50	2.00	7.03	6.38
LST-17	90.73	73.93	135.27	71.20	40.20	34.67	36.06	36.47	2.17	2.07	5.98	5.03
LST-6	79.73	53.07	140.33	70.93	36.87	35.67	49.68	35.52	3.00	2.00	5.38	5.52
Leader	82.33	51.87	140.67	73.00	32.73	31.40	72.13	67.14	2.33	2.07	7.45	6.77
Malintka	81.07	69.60	135.20	66.67	31.07	34.00	13.92	12.76	2.00	2.07	3.62	3.54
Spectrum	91.13	70.73	139.60	76.67	33.13	32.07	63.12	59.76	2.00	2.07	7.40	6.64
Testers												
alc-IIHR-2050	90.80	67.60	141.67	76.33	34.80	34.27	50.50	43.39	2.33	2.00	6.02	5.51
nor-RM-1	65.87	71.33	141.33	78.00	31.60	31.07	71.75	69.61	2.67	2.33	7.13	7.53
rin-Rutgers	88.40	81.33	141.60	73.67	36.27	34.93	42.87	27.71	2.17	2.33	4.21	4.87
Olive Green#	90.33	70.33	144.20	77.67	32.07	34.40	8.38	8.83	2.84	2.00	1.85	2.31
Check												
PTH-2	75.40	67.93	144.00	71.13	34.47	33.00	75.84	67.04	4.17	3.71	5.72	5.19
Grand Mean	82.66	68.09	140.09	72.86	34.75	34.10	57.19	52.98	2.55	2.40	5.54	5.54
CD (5%)	7.68	6.48	5.61	4.62	3.97	3.90	3.78	15.22	0.50	0.58	0.45	1.23
CD (1%)	10.08	8.23	7.09	5.78	4.92	4.80	4.68	19.78	0.70	0.73	0.56	1.59

#gene unidentified

Cont. Table 2

Parents	Polar/Equatorial (P/E) ratio		Total Fruit Yield (kg plant-1)		Total Soluble Solids (°Brix)		Dry Matter (%)		Lycopene (mg/100 gm of fresh weight)		Titratable Acidity (mg/100 mL fruit juice)	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Lines												
SMZ-867	1.58	1.48	1.71	0.93	7.29	5.07	7.16	7.21	3.09	2.21	0.74	0.59
CLN 1621L	0.98	0.89	1.66	1.46	5.64	4.93	7.41	6.66	3.27	3.34	0.58	0.70
PAU 114	1.29	1.19	1.98	1.46	4.17	4.40	5.40	5.94	4.03	2.55	0.68	0.68
FL-556	1.22	1.15	1.80	1.27	4.86	4.50	5.51	5.73	2.96	3.03	0.61	0.43
PAU 2381	0.96	1.14	2.24	1.75	4.24	4.87	5.17	5.81	5.02	4.66	0.52	0.66
LT-44	0.98	0.91	1.83	1.07	5.57	5.23	7.13	5.91	3.51	3.03	0.81	0.61
Punjab Ratta	1.31	1.09	2.40	2.01	4.86	5.00	5.74	7.36	6.59	5.72	0.40	0.66
Roma	2.46	2.21	1.10	0.69	3.99	4.10	6.23	5.47	3.34	2.25	0.64	0.45
LT-42	1.22	1.15	1.60	1.07	5.45	4.50	6.84	5.71	4.11	2.58	0.47	0.42
LST-17	0.97	1.04	1.73	1.47	5.07	5.07	6.28	7.05	3.69	2.58	0.89	0.45
LST-6	1.12	1.37	1.38	1.00	4.53	5.07	4.75	5.63	4.81	2.61	0.69	0.69
Leader	1.42	1.23	1.90	1.68	3.88	4.17	4.60	5.53	3.15	2.70	0.58	0.67
Malintka	0.87	1.16	1.50	1.46	3.01	4.37	7.27	6.26	4.13	2.40	1.01	0.61
Spectrum	1.27	1.19	1.12	1.09	4.73	4.33	4.59	5.71	2.42	2.67	0.60	0.49
Testers												
alc-IIHR-2050	1.57	1.64	1.02	0.81	4.84	5.13	5.61	6.30	3.10	3.80	0.69	0.55
nor-RM-1	1.09	1.07	1.62	0.71	4.19	4.13	5.94	6.42	0.91	0.26	0.67	0.45
rin-Rutgers	1.10	1.11	1.49	1.30	3.64	4.40	5.33	4.96	3.71	3.20	0.80	0.59
Olive Green	0.87	0.91	0.50	0.31	4.84	6.17	8.73	7.09	1.02	0.72	0.87	0.51
Check												
PTH-2	0.84	0.91	2.45	1.85	4.38	3.52	5.52	4.20	4.03	3.20	0.59	0.52
Grand Mean	1.22	1.20	1.63	1.23	4.69	4.68	6.06	6.05	3.52	2.82	0.68	0.56
CD (5%)	0.20	0.22	0.42	0.73	0.43	0.79	0.53	1.39	0.98	1.17	0.26	0.32
CD (1%)	0.23	0.25	0.52	0.93	0.55	1.01	0.67	1.81	1.26	1.52	0.30	0.38

Table 3. Mean performance of crosses for different traits in main (E_1) and spring (E_2) season

Cross combinations	Pollen Viability (%)		Days from Transplanting to the First Harvest		Harvesting Span(Days)		Average Fruit Weight (g)		Number of Locules per Fruit		Pericarp Thickness (mm)	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
SMZ-867×*alc*-IIHR-2050	73.73	51.67	136.33	71.33	35.73	35.27	43.16	36.02	2.00	2.07	6.65	5.75
SMZ-867×*nor*-RM-1	80.80	61.93	141.60	65.80	36.93	43.60	33.02	48.44	2.33	2.00	6.15	5.98
SMZ-867×*rin*-Rutgers	94.27	53.80	140.13	71.47	35.80	33.20	34.78	35.94	2.00	2.00	6.02	4.77
SMZ-867×Olive Green	63.33	57.00	137.20	67.67	32.00	39.40	43.20	44.86	2.00	2.00	3.83	5.79
CLN 1621L×*alc*-IIHR-2050	89.93	63.07	140.67	70.27	39.40	37.60	76.35	59.78	3.67	2.93	5.09	6.17
CLN 1621L×*nor*-RM-1	91.80	66.67	140.40	68.93	33.60	38.87	51.04	49.58	2.50	2.53	4.39	5.14
CLN 1621L×*rin*-Rutgers	67.53	64.33	138.27	69.73	39.40	35.53	46.80	54.93	2.84	3.27	4.73	4.50
CLN 1621L×Olive Green	63.60	65.47	140.33	67.27	39.93	34.93	21.08	17.65	2.34	2.47	4.30	4.08
PAU 114×*alc*-IIHR-2050	77.87	55.33	131.33	71.80	42.40	30.53	85.36	75.99	2.00	2.07	8.41	5.75
PAU 114×*nor*-RM-1	81.20	58.27	134.47	66.33	34.80	33.07	63.67	44.32	2.00	2.00	8.25	6.49
PAU 114×*rin*-Rutgers	61.40	84.13	139.47	67.40	34.73	38.33	37.55	38.85	2.33	2.00	5.80	5.80
PAU 114×Olive Green	86.73	69.53	141.33	73.07	30.40	30.93	23.43	32.55	2.00	2.00	4.36	4.32
FL-556×*alc*-IIHR-2050	63.47	58.00	131.93	68.80	42.53	39.00	58.85	59.50	2.00	2.07	6.29	6.62
FL-556×*nor*-RM-1	79.33	64.47	135.20	76.27	31.47	37.40	67.05	65.28	2.00	2.07	8.31	6.41
FL-556×*rin*-Rutgers	58.67	55.60	141.33	68.80	37.13	40.00	46.57	47.79	2.34	2.00	6.27	5.47
FL-556×Olive Green	77.47	76.80	143.07	68.87	34.07	35.93	26.00	25.79	2.00	2.00	4.29	4.21
PAU 2381×*alc*-IIHR-2050	74.73	53.87	134.00	75.13	40.47	29.40	76.12	71.72	2.00	2.07	6.13	5.95
PAU 2381×*nor*-RM-1	89.93	65.53	135.53	73.40	43.00	32.00	79.27	85.42	2.34	2.37	7.64	7.96
PAU 2381×*rin*-Rutgers	62.47	62.47	141.40	70.33	36.40	41.00	50.81	63.84	2.33	2.40	5.42	6.25
PAU 2381×Olive Green	82.13	68.67	140.33	72.27	36.47	35.60	23.29	28.47	2.00	2.33	4.53	4.23
LT-44×*alc*-IIHR-2050	80.67	77.53	132.67	68.33	41.47	37.73	91.35	86.89	4.17	2.87	6.60	7.13
LT-44×*nor*-RM-1	81.93	51.67	138.00	74.27	35.73	33.20	75.78	53.51	2.38	2.53	4.97	5.15
LT-44×*rin*-Rutgers	58.73	66.33	131.53	68.80	42.67	37.80	82.03	75.61	4.84	3.93	5.87	6.50
LT-44×Olive Green	64.60	57.73	141.80	67.27	35.73	43.00	31.03	33.29	3.33	3.53	4.54	4.44
Punjab Ratta×*alc*-IIHR-2050	71.33	50.20	132.20	67.13	42.47	41.27	63.98	65.29	2.00	2.00	7.21	6.92
Punjab Ratta×*nor*-RM-1	89.33	50.67	134.00	71.27	40.73	37.07	63.61	68.02	2.00	2.07	7.64	7.55
Punjab Ratta×*rin*-Rutgers	71.00	52.07	139.80	67.27	34.33	35.40	43.47	52.62	2.00	2.07	6.19	5.96

Cont.Table 3

Cross combinations	Pollen Viability (%)		Days from Transplanting to the First Harvest		Harvesting Span (Days)		Average Fruit Weight (g)		Number of Locules per Fruit		Pericarp Thickness (mm)	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Roma×*alc*-IIHR-2050	72.53	83.93	131.00	73.60	42.00	31.93	56.79	58.17	2.00	2.00	4.69	5.81
Roma×*nor*-RM-1	87.33	53.13	142.53	71.47	37.33	33.33	85.64	90.90	2.13	2.13	6.67	6.45
Roma×*rin*-Rutgers	81.27	52.13	138.33	73.67	35.73	30.93	45.22	70.03	2.34	2.00	5.90	6.73
Roma×Olive Green	84.40	63.00	142.00	71.00	33.33	32.27	26.04	24.32	2.07	2.00	5.19	4.90
LT-42×*alc*-IIHR-2050	88.07	64.40	137.33	69.80	41.93	37.47	55.88	53.38	2.17	2.00	7.14	5.71
LT-42×*nor*-RM-1	79.33	53.47	140.33	70.67	32.70	31.87	61.34	57.27	2.00	2.07	7.05	7.27
LT-42×*rin*-Rutgers	79.33	52.20	138.00	72.73	37.57	32.33	60.15	66.96	2.33	2.13	6.05	6.48
LT-42×Olive Green	82.07	72.60	140.27	67.37	41.27	37.47	30.21	33.12	2.22	2.00	5.27	4.87
LST-17×*alc*-IIHR-2050	93.47	70.67	131.07	73.67	40.40	35.53	45.17	67.39	2.33	2.53	6.42	5.93
LST-17×*nor*-RM-1	64.20	53.67	137.00	68.60	32.80	35.60	50.36	54.18	2.00	2.00	6.59	6.43
LST-17×*rin*-Rutgers	88.67	85.00	138.73	68.60	36.33	35.27	42.63	47.62	2.33	2.07	4.45	5.03
LST-17×Olive Green	66.27	52.40	141.40	67.00	35.00	38.27	17.39	23.43	2.00	2.00	4.66	3.72
LST-6×*alc*-IIHR-2050	92.07	82.00	137.27	69.20	35.87	37.00	52.84	59.59	2.17	2.00	5.99	6.21
LST-6×*nor*-RM-1	81.40	66.00	138.20	66.87	38.20	41.40	36.37	47.97	2.00	2.00	6.03	6.28
LST-6×*rin*-Rutgers	60.73	71.00	136.80	66.33	42.67	39.07	28.14	40.76	2.00	2.00	5.42	5.44
LST-6×Olive Green	72.87	63.67	141.07	73.00	33.87	36.40	17.42	21.48	2.00	2.00	3.95	3.89
Leader×*alc*-IIHR-2050	93.33	52.67	135.60	71.93	41.27	32.93	41.70	53.69	2.17	2.13	7.11	7.73
Leader×*nor*-RM-1	95.47	51.07	132.00	77.47	42.20	36.33	73.38	78.75	2.00	2.07	6.38	7.59
Leader×*rin*-Rutgers	91.60	50.20	140.40	69.40	31.33	35.33	39.69	38.02	2.50	2.20	7.26	5.54
Leader×Olive Green	60.73	64.27	141.07	74.67	37.33	28.27	20.44	24.06	2.00	2.00	4.27	3.89
Malintka×*alc*-IIHR-2050	95.07	81.80	139.67	68.67	31.07	33.73	31.10	27.55	2.00	2.07	3.44	4.23
Malintka×*nor*-RM-1	83.33	55.67	142.93	67.27	30.67	43.53	36.95	32.24	2.00	2.00	5.05	4.53
Malintka×*rin*-Rutgers	62.67	53.73	135.60	69.27	39.00	38.40	27.14	21.72	2.00	2.07	4.15	3.87
Malintka×Olive Green	62.73	64.13	137.67	70.93	32.80	39.07	18.35	22.24	2.00	2.07	3.79	3.63
Spectrum×*alc*-IIHR-2050	92.07	77.73	134.40	68.80	41.00	29.93	48.50	48.65	2.00	2.00	7.65	5.56
Spectrum×*nor*-RM-1	82.73	70.60	140.47	73.53	38.80	32.93	71.23	72.65	2.00	2.00	7.19	5.77
Spectrum×*rin*-Rutgers	94.67	64.73	141.40	68.27	40.27	40.93	46.33	54.27	2.00	2.13	4.23	5.40
Spectrum×Olive Green	75.07	60.40	138.87	70.07	34.67	37.27	46.65	43.82	2.00	2.07	6.59	3.69
CD (5%)	**7.68**	**6.48**	**5.61**	**4.62**	**3.97**	**3.90**	**3.78**	**15.22**	**0.50**	**0.58**	**0.45**	**1.23**
CD (1%)	**10.08**	**8.23**	**7.09**	**5.78**	**4.92**	**4.80**	**4.68**	**19.78**	**0.70**	**0.53**	**0.56**	**1.59**

Cont. Table 3.

Cross combinations	Polar/Equatorial (P/E) ratio		Total Fruit Yield (kg plant-1)		Total Soluble Solids (°Brix)		Dry Matter (%)		Lycopene (mg/100 gm of fresh weight)		Titratable Acidity (mg /100 ml fruit juice)	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
SMZ-867 × *alc*-IIHR-2050	1.23	1.25	2.21	1.02	5.17	4.43	6.19	5.07	3.03	2.80	0.71	0.64
SMZ-867 × *nor*-RM-1	1.21	1.16	1.83	1.90	6.70	4.67	8.49	5.40	4.01	3.36	0.88	0.89
SMZ-867 × *rin*-Rutgers	1.35	1.27	1.57	1.65	4.86	4.97	6.50	6.68	4.24	2.79	0.62	0.79
SMZ-867 × Olive Green	1.10	1.17	2.14	0.97	6.72	4.43	7.50	6.45	4.00	3.43	0.83	0.70
CLN 1621L × *alc*-IIHR-2050	0.93	0.89	2.56	1.84	4.74	4.23	5.04	5.10	3.00	2.79	0.72	0.73
CLN 1621L × *nor*-RM-1	1.10	1.29	1.93	1.50	4.87	4.13	5.92	5.11	3.93	3.34	0.83	0.77
CLN 1621L × *rin*-Rutgers	0.90	0.91	1.57	1.71	5.29	4.40	6.91	6.15	2.99	3.30	0.95	0.72
CLN 1621L × Olive Green	0.84	0.89	1.96	1.44	6.60	5.37	7.16	6.32	3.87	3.15	0.64	0.66
PAU 114 × *alc*-IIHR-2050	1.19	1.11	1.92	1.32	4.59	4.17	6.81	5.83	3.69	4.10	0.77	0.89
PAU 114 × *nor*-RM-1	1.12	1.36	2.30	1.42	4.68	5.20	6.34	6.23	4.72	2.84	0.61	0.77
PAU 114 × *rin*-Rutgers	1.13	1.17	0.93	1.38	5.03	3.90	6.59	7.20	3.79	2.53	0.69	0.61
PAU 114 × Olive Green	1.08	0.98	2.08	1.42	6.34	5.37	7.28	7.49	4.19	3.15	0.66	0.68
FL-556 × *alc*-IIHR-2050	1.27	1.30	1.26	1.88	4.53	4.90	6.00	6.33	4.63	3.13	0.76	0.55
FL-556 × *nor*-RM-1	1.15	1.03	1.50	1.24	4.45	4.30	5.21	5.87	5.61	2.82	0.82	0.79
FL-556 × *rin*-Rutgers	1.16	1.01	1.62	1.60	4.81	3.90	6.73	5.05	4.52	3.43	0.71	0.80
FL-556 × Olive Green	1.03	0.99	1.48	1.15	5.93	5.43	8.00	7.54	3.13	2.93	0.74	0.58
PAU 2381 × *alc*-IIHR-2050	1.34	1.26	2.09	1.82	3.98	4.13	5.61	5.63	5.03	4.00	0.59	0.67
PAU 2381 × *nor*-RM-1	1.13	1.03	2.64	1.39	4.82	5.60	5.59	6.48	6.48	2.93	0.67	0.68
PAU 2381 × *rin*-Rutgers	1.03	1.30	1.51	1.99	4.03	4.40	4.99	5.35	3.51	2.41	0.70	0.65
PAU 2381 × Olive Green	1.13	0.95	1.57	1.48	6.21	5.10	7.65	7.48	5.71	2.38	0.50	0.63
LT-44 × *alc*-IIHR-2050	0.99	1.13	1.69	1.88	4.18	4.37	5.02	5.43	5.08	2.89	0.56	0.61
LT-44 × *nor*-RM-1	0.93	0.96	2.26	1.82	5.18	4.50	6.13	6.24	3.55	3.42	0.80	0.79
LT-44 × *rin*-Rutgers	0.86	0.91	2.44	1.99	4.78	4.37	4.93	7.20	2.69	3.06	0.56	0.71
LT-44 × Olive Green	1.13	1.06	1.63	1.27	6.51	5.30	6.91	6.26	3.70	4.80	0.56	0.46
Punjab Ratta × *alc*-IIHR2050	1.13	1.23	1.66	1.47	4.90	4.57	6.52	5.89	2.56	3.00	0.80	0.70
Punjab Ratta × *nor*-RM-1	1.18	1.10	2.05	1.08	3.13	5.89	5.61	6.23	3.49	1.91	0.75	0.68
Punjab Ratta × *rin*-Rutgers	1.11	1.04	1.78	1.34	4.77	4.40	5.58	5.89	3.72	2.17	0.63	0.74
Punjab Ratta × Olive Green	1.02	0.97	1.95	1.39	6.11	5.70	7.40	8.04	4.08	4.07	0.77	0.75

Cont. Table 3

Cross combinations	Polar/Equatorial (P/E) ratio		Total Fruit Yield (kg plant-1)		Total Soluble Solids (°Brix)		Dry Matter (%)		Lycopene (mg/100 gm of fresh weight)		Titratable Acidity (mg /100 ml fruit juice)	
	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2	E_1	E_2
Roma ×*nor*-RM-1	1.43	1.44	2.61	1.94	4.95	4.70	6.26	5.94	4.66	3.11	0.76	0.67
Roma ×*rin*-Rutgers	1.51	1.13	2.10	1.20	4.05	5.20	5.42	7.01	5.19	2.26	0.64	0.77
Roma × Olive Green	1.51	1.42	1.56	1.17	6.05	5.53	7.17	7.43	3.18	3.99	0.81	0.64
LT-42 × *alc*-IIHR-2050	1.30	1.24	2.17	1.06	3.81	4.33	5.20	5.35	3.13	2.99	0.69	0.72
LT-42 × *nor*-RM-1	1.14	1.00	2.17	1.91	3.94	5.30	5.40	5.84	2.73	2.91	0.69	0.57
LT-42 × *rin*-Rutgers	1.10	1.17	1.81	1.90	3.94	4.37	4.61	4.48	4.36	3.43	0.70	0.71
LT-42 × Olive Green	1.01	1.00	1.77	1.02	5.28	5.67	8.38	8.33	3.83	3.89	0.56	0.49
LST-17 × *alc*-IIHR-2050	1.08	1.02	2.00	1.17	4.18	4.20	5.39	6.05	3.56	2.68	0.66	0.67
LST-17 × *nor*-RM-1	0.95	0.99	1.59	1.36	4.88	4.77	5.33	6.25	4.95	2.14	0.67	0.79
LST-17 × *rin*-Rutgers	0.91	1.01	1.56	1.82	4.08	4.37	4.95	7.19	3.52	2.92	0.74	0.74
LST-17 × Olive Green	1.07	1.00	1.10	1.28	6.48	5.67	7.04	7.91	4.38	3.64	0.61	0.54
LST-6 × *alc*-IIHR-2050	0.98	1.39	1.79	1.23	5.72	4.33	6.16	5.48	5.06	2.68	0.72	0.72
LST-6 × *nor*-RM-1	0.85	1.03	2.00	1.35	6.38	4.33	7.29	5.98	3.81	3.82	1.28	0.74
LST-6 × *rin*-Rutgers	1.15	1.15	1.72	1.63	4.43	4.60	5.31	6.19	3.34	2.35	0.86	0.77
LST-6 × Olive Green	1.03	0.99	1.86	1.45	6.86	5.73	7.40	7.81	4.23	2.58	0.68	0.62
Leader ×*alc*-IIHR-2050	1.29	1.34	0.94	1.44	4.43	5.20	5.92	6.30	2.83	2.57	0.67	0.73
Leader ×*nor*-RM-1	1.10	1.10	1.97	1.19	4.27	4.20	5.67	5.72	3.87	2.96	0.79	0.54
Leader ×*rin*-Rutgers	1.02	1.21	1.19	1.18	4.30	5.07	6.08	6.39	4.27	2.20	0.77	0.94
Leader × Olive Green	1.03	1.02	1.12	1.29	5.62	5.13	6.71	7.01	5.51	2.80	0.64	0.56
Malintka × *alc*-IIHR-2050	1.12	1.11	1.61	1.96	4.62	4.67	5.37	6.79	2.56	3.00	0.72	0.88
Malintka × *nor*-RM-1	0.95	0.92	1.29	1.19	4.92	4.37	6.49	6.29	4.94	2.66	0.80	0.78
Malintka × *rin*-Rutgers	1.00	1.05	0.84	1.19	4.37	4.70	5.43	6.15	3.21	2.33	0.79	0.81
Malintka × Olive Green	1.03	0.98	1.32	1.31	5.85	5.37	7.16	6.99	4.28	2.38	0.82	0.77
Spectrum × *alc*-IIHR-2050	1.32	1.18	1.18	1.03	4.41	5.21	5.58	5.82	2.94	2.13	0.72	0.55
Spectrum × *nor*-RM-1	1.18	1.06	2.00	1.78	4.43	4.50	6.44	5.45	4.34	1.89	0.67	0.81
Spectrum × *rin*-Rutgers	1.16	1.05	1.46	1.42	6.13	4.10	7.50	5.33	4.86	3.33	0.83	0.71
Spectrum × Olive Green	1.25	0.98	1.45	1.30	4.22	5.60	5.47	7.74	2.73	2.26	0.73	0.44
CD (5%)	**0.20**	**0.22**	**0.42**	**0.73**	**0.43**	**0.79**	**0.53**	**1.39**	**0.98**	**1.17**	**0.26**	**0.32**
CD (1%)	**0.23**	**0.25**	**0.52**	**0.93**	**0.55**	**1.01**	**0.67**	**1.81**	**1.26**	**1.52**	**0.30**	**0.38**

Table 4. Top performing hybrids for various characters in main (E_1) and spring (E_2) season

Traits		Best crosses *Per se*	Best heterotic crosses over better parent	Best heterotic crosses over check (PTH-2)
Pollen Viability (%)	E_1	Leader × *nor*-RM-1 (95.47) Malintka ×*alc*-IIHR-2050 (95.07) Spectrum × *rin*-Rutgers (94.67) SMZ-867 × *rin*-Rutgers (94.27)	PAU 2381 × *nor*-RM-1 (36.53**) Leader × *nor*-RM-1 (15.96**) SMZ-867 × *nor*-RM-1 (15.43**) Punjab Ratta × *nor*-RM-1 (12.61**)	Leader × *nor*-RM-1 (26.62**) Malintka × *alc*-IIHR-2050 (26.09**) Spectrum × *rin*-Rutgers (25.56**) SMZ-867 × *rin*-Rutgers (25.03**)
	E_2	LST-17 × *rin*-Rutgers (85.00) PAU 114 × *rin*-Rutgers (84.13) Roma ×*alc*-IIHR-2050 (83.93) LST-6 ×*alc*-IIHR-2050 (82.00)	LST-6 × *alc*-IIHR-2050 (21.30**) Malintka × *alc*-IIHR-2050 (17.53**) LT-44 × *alc*-IIHR-2050 (14.69**) Roma × *alc*-IIHR-2050 (10.92**)	LST-17 × *rin*-Rutgers (25.13**) PAU 114 × *rin*-Rutgers (23.85**) Roma × *alc*-IIHR-2050 (23.55**) LST-6 × *alc*-IIHR-2050 (20.71**)
Days from Transplanting to the First Harvest	E_1	Roma ×*alc*-IIHR-2050 (72.53) LST-17 ×*alc*-IIHR-2050 (93.47) PAU 114 ×*alc*-IIHR-2050 (77.87) LT-44 × *rin*-Rutgers (58.73)	Punjab Ratta × Olive Green (-24.50**) Roma × *alc*-IIHR-2050 (-20.12**) LST-17 × *alc*-IIHR-2050(3.02) PAU 114 × *alc*-IIHR-2050 (-14.24**)	Roma × *alc*-IIHR-2050 (-3.81) LST-17 × *alc*-IIHR-2050 (23.97**) PAU 114 × *alc*-IIHR-2050 (3.28) LT-44 × *rin*-Rutgers (-22.11**)
	E_2	SMZ-867 × *nor*-RM-1 (65.80) PAU 114 × *nor*-RM-1 (66.33) LST-6 × *rin*-Rutgers (66.33) LST-6 ×*nor*-RM-1 (66.87)	SMZ-867 × *nor*-RM-1 (-15.64**) PAU 114 × *nor*-RM-1 (-14.96**) LT-44 × Olive Green (-14.71**) LST-6 × *nor*-RM-1 (-14.27**)	SMZ-867 × *nor*-RM-1 (-7.49**) PAU 114 × *nor*-RM-1 (-6.75**) LST-6 × *rin*-Rutgers (-6.75**) LST-6 × *nor*-RM-1 (-5.99**)
Harvesting Span (Days)	E_1	PAU 2381 × *nor*-RM-1 (43.00) LT-44 × *rin*-Rutgers (42.67) LST-6 × *rin*-Rutgers (42.67) FL-556 ×*alc*-IIHR-2050 (42.53)	Leader × *nor*-RM-1 (28.93**) LT-42 × Olive green (27.89**) PAU 114 × *alc*-IIHR-2050 (21.84**) Roma × *alc*-IIHR-2050 (20.69**) LT-44 × *alc*-IIHR-2050 (19.17**)	PAU 2381 × *nor*-RM-1 (24.75**) LT-44 × *rin*-Rutgers (23.79**) LST-6 × *rin*-Rutgers (23.79**) FL-556 × alc-IIHR-2050 (23.38**) Punjab Ratta × *alc*-IIHR-2050 (23.21**)
	E_2	SMZ-867 × *nor*-RM-1 (43.60) Malintka × *nor*-RM-1 (43.53) LT-44 × Olive Green (43.00) LST-6 × *nor*-RM-1 (41.40)	Malintka × *nor*-RM-1 (28.03**) CLN1621L × *nor*-RM-1 (25.10**) LT-44 × Olive Green (25.00**) SMZ-867 × *nor*-RM-1 (20.21**)	SMZ-867 × *nor*-RM-1 (32.12**) Malintka × *nor*-RM-1 (31.91**) LT-44 × Olive Green (30.30**) LST-6 × *nor*-RM-1 (25.45**)
Average Fruit Weight (g)	E_1	LT-44 ×*alc*-IIHR-2050 (91.35) Roma × *nor*-RM-1 (85.64) PAU 114 × *alc*-IIHR-2050 (85.36) LT-44 × *rin*-Rutgers (82.03)	SMZ-867 × Olive Green (109.71**) PAU 114 × *alc*-IIHR-2050 (11.84**) Roma × *nor*-RM-1 (19.36**) LT-44 × *alc*-IIHR-2050 (2.81)	LT-44 × *alc*-IIHR-2050 (20.45**) Roma × *nor*-RM-1 (12.92**) PAU 114 × *alc*-IIHR-2050 (12.55**) LT-44 × *rin*-Rutgers (8.16*)
	E_2	Roma × *nor*-RM-1 (90.90) LT-44 ×*alc*-IIHR-2050 (86.89) PAU 2381 × *nor*-RM-1 (85.42) Leader × *nor*-RM-1 (78.75)	SMZ-867 × Olive Green (111.60**) LST-17 × *rin*-Rutgers (30.57**) LST-17 × *alc*-IIHR-2050 (55.31**) Roma × *rin*-Rutgers (37.61**) Roma × *nor*-RM-1 (30.58**)	Roma × *nor*-RM-1 (35.59**) LT-44 × *alc*-IIHR-2050 (29.61**) PAU 2381 × *nor*-RM-1 (27.42**) Leader × *nor*-RM-1 (17.47**) PAU 114 × *alc*-IIHR-2050 (13.35)

Cont. Table 4.

Traits		Best crosses *Per se*	Best heterotic crosses over better parent	Best heterotic crosses over check (PTH-2)
Number of Loculesper Fruit	E_1	SMZ-867 × *alc*-IIHR-2050 (2.00) PAU 114 × *alc*-IIHR-2050 (2.00) PAU 114 × Olive Green (2.00) FL-556 × *nor*-RM-1 (2.00)	PAU2381 × *alc*-IIHR-2050 (-42.86**) PAU 2381 × Olive Green (-42.86**) PAU 2381 × *rin*-Rutgers (-33.43**)	SMZ-867 × *alc*-IIHR-2050 (-52.04**) PAU 114 × *alc*-IIHR-2050 (-52.04**) PAU 114 × Olive Green (-52.04**) FL-556 × *nor*-RM-1(-52.04**)
	E_2	SMZ-867 × *nor*-RM-1 (2.00) PAU 114 × *rin*-Rutgers (2.00) FL-556 × *rin*-Rutgers (2.00) LT-42 × *alc*-IIHR-2050 (2.00)	LT-44 × *nor*-RM-1 (-39.32**) LT-44 × *alc*-IIHR-2050 (-46.51**) CLN1621L × Olive Green (-33.78**) CLN1621L × *nor*-RM-1 (-32.17**)	SMZ-867 × *nor*-RM-1 (-46.09**) PAU 114 × *rin*-Rutgers (-46.09**) FL-556 × *rin*-Rutgers (-46.09**) LT-42 × *alc*-IIHR-2050 (-46.09**)
Pericarp Thickness (mm)	E_1	PAU 114 ×*alc*-IIHR-2050 (8.41) FL-556 × *nor*-RM-1 (8.31) PAU 114 × *nor*-RM-1 (8.25) Spectrum ×*alc*-IIHR-2050 (7.65)	SMZ-867 × *rin*-Rutgers (41.65**) PAU 114 × *alc*-IIHR-2050 (39.70**) FL-556 × *nor*-RM-1 (16.55**) PAU 114 × *nor*-RM-1 (13.71**)	PAU 114 × alc-IIHR-2050 (47.03**) FL-556 × *nor*-RM-1 (45.28**) PAU 114 × *nor*-RM-1 (44.23**) Spectrum × *alc*-IIHR-2050 (33.74**)
	E_2	PAU 2381 × *nor*-RM-1 (7.96) Leader ×*alc*-IIHR-2050 (7.73) Leader × *nor*-RM-1 (7.59) Punjab Ratta × *nor*-RM-1 (7.55)	SMZ-867 × Olive Green (47.33**) Roma × *rin*-Rutgers (38.19**)	PAU 2381 × *nor*-RM-1 (53.37**) Leader × *alc*-IIHR-2050 (48.94**) Leader × *nor*-RM-1 (46.24**) Punjab Ratta × *nor*-RM-1 (45.47**)
Polar/Equatorial (P/E) ratio	E_1	Roma ×*alc*-IIHR-2050 (1.90) Roma × Olive Green (1.51) Roma × *rin*-Rutgers (1.51) Roma × *nor*-RM-1 (1.43)	Malintka × Olive Green (18.39**) PAU 2381 × Olive Green (17.71**) LT-44 × Olive Green (15.31**) CLN1621L × Olive Green (12.24**)	Roma × *alc*-IIHR-2050 (126.19**) Roma × Olive Green (79.76**) Roma × *rin*-Rutgers (79.76**) Roma × *nor*-RM-1 (70.24**) SMZ-867 × *rin*-Rutgers (60.71**)
	E_2	Roma ×*alc*-IIHR-2050 (1.66) Roma × *nor*-RM-1 (1.44) Roma × Olive Green (1.42) LST-6 ×*alc*-IIHR-2050 (1.39)	CLN1621L × *nor*-RM-1 (20.56**) LT-44 × Olive Green (16.48**) PAU 114 × *nor*-RM-1 (14.29**)	Roma × *alc*-IIHR-2050 (82.42**) Roma × *nor*-RM-1 (58.24**) Roma × Olive Green (56.04**) LST-6 × *alc*-IIHR-2050 (52.75**)
Total Fruit Yield (kg plant^{-1})	E_1	PAU 2381 × *nor*-RM-1 (2.64) Roma × *nor*-RM-1 (2.61) CLN1621L ×*alc*-IIHR-2050 (2.56) LT-44 × *rin*-Rutgers (2.44)	Roma × *nor*-RM-1 (54.44**) CLN1621L × *alc*-IIHR-2050 (54.22**) Roma × *alc*-IIHR-2050 (43.64**) Roma × Olive Green (41.82**)	PAU 2381 × *nor*-RM-1 (17.76*) Roma × *nor*-RM-1 (16.53*)
	E_2	PAU 2381 × *rin*-Rutgers (1.99) LT-44 × *rin*-Rutgers (1.99) Malintka ×*alc*-IIHR-2050 (1.11) Roma × *nor*-RM-1 (1.94)	Roma × *nor*-RM-1 (173.24**) SMZ-867 × *nor*-RM-1 (104.30**) LT-42 × *nor*-RM-1 (78.50*) LT-44 × *alc*-IIHR-2050 (75.70*)	PAU 2381 × *rin*-Rutgers (27.57*) LT-44 × *rin*-Rutgers (27.57*)

Cont. Table 4.

Traits		Best crosses Per se	Best heterotic crosses over better parent	Best heterotic crosses over check (PTH-2)
Total Soluble Solids (°Brix)	E_1	LST-6 × Olive Green (6.86) SMZ-867 × Olive Green (6.72) SMZ-867 × *nor*-RM-1 (6.70) CLN1621L × Olive Green (6.60)	LST-6 × Olive Green (41.74**) LST-6 × *nor*-RM-1 (40.84**) PAU 114 × Olive Green (30.99**) Spectrum × *rin*-Rutgers (29.60**)	LST-6 × Olive Green (56.62**) SMZ-867 × Olive Green (53.42**) SMZ-867 × *nor*-RM-1 (52.97**) CLN1621L × Olive Green (50.68**)
	E_2	Punjab Ratta × *nor*-RM-1 (5.89) LST-6 × Olive Green (5.73) Punjab Ratta × Olive Green (5.70) LT-42 × Olive Green (5.67)	Spectrum × *nor*-RM-1 (20.32**) PAU 114 × *nor*-RM-1 (18.18**) Roma × *rin*-Rutgers (18.18*) Punjab Ratta × *nor*-RM-1 (17.8**)	Punjab Ratta × *nor*-RM-1 (67.33**) LST-6 × Olive Green (62.78**) Punjab Ratta × Olive Green (61.93**) LT-42 × Olive Green (61.08**) LST-17 × Olive Green (61.08**)
Dry Matter (%)	E_1	SMZ-867 × *nor*-RM-1 (8.49) LT-42 × Olive Green (8.33) FL-556 × Olive Green (8.00) PAU 2381 × Olive Green (7.65)	Spectrum × *rin*-Rutgers (40.71**) FL-556 × *rin*-Rutgers (26.27**) LST-6 × *nor*-RM-1 (22.73**) PAU 114 × *rin*-Rutgers (22.04**)	SMZ-867 × *nor*-RM-1 (53.80**) LT-42 × Olive Green (51.81**) FL-556 × Olive Green (44.93**) PAU 2381 × Olive Green (38.59**)
	E_{2a}	LT-42 × Olive Green (8.33) Punjab Ratta × Olive Green (8.04) LST-17 × Olive Green (7.91) LST-6 × Olive Green (7.81)	Roma × *rin*-Rutgers (28.15*) LST-6 × *rin*-Rutgers (27.71*) LT-44 × *rin*-Rutgers (21.83*) PAU 114 × *rin*-Rutgers (21.21*)	LT-42 × Olive Green (98.33**) Punjab Ratta × OliveGreen (91.43**) LST-17 × Olive Green (88.33**) LST-6 × Olive Green (85.93**) Spectrum × Olive Green (84.29**)
Lycopene (mg/100 gm of fresh weight)	E_1	PAU 2381 × *nor*-RM-1 (6.48) PAU 2381 × Olive Green (5.71) FL-556 × *nor*-RM-1 (5.61) Leader × Olive Green (5.51)	FL-556 × *nor*-RM-1 (89.53**) Spectrum × *nor*-RM-1 (79.34**) Leader × Olive Green (74.92**) Roma × *rin*-Rutgers (39.89**)	PAU 2381 × *nor*-RM-1 (60.79**) PAU 2381 × Olive Green (41.69**) FL-556 × *nor*-RM-1 (39.21**) Leader × Olive Green (36.72**)
	E_2	LT-44 × Olive Green (4.80) PAU 114 ×*alc*-IIHR-2050 (4.10) Punjab Ratta × Olive Green (4.07) PAU 2381 ×*alc*-IIHR-2050 (4.00)	Roma × Olive Green (77.33**) SMZ-867 × Olive Green (55.20*) SMZ-867 × *nor*-RM-1 (52.04*) LT-42 × Olive Green (50.78*)	LT-44 × Olive Green (50.00**)
Titratable Acidity (mg /100 ml fruit juice)	E_1	LST-6 × *nor*-RM-1 (1.28) CLN1621L × *rin*-Rutgers (0.95) SMZ-867 × *nor*-RM-1 (0.88) LST-6 × *rin*-Rutgers (0.86)	LST-6 × *nor*-RM-1 (85.51**) CLN1621L × *nor*-RM-1 (23.88*) FL-556 × *nor*-RM-1 (22.39*) SMZ-867 × *nor*-RM-1 (18.92*) CLN1621L × *rin*-Rutgers (18.75*)	LST-6 × *nor*-RM-1 (116.95**) CLN1621L × *rin*-Rutgers (61.02**) SMZ-867 × *nor*-RM-1 (49.15**) LST-6 × *rin*-Rutgers (45.76**)
	E_2	Leader × *rin*-Rutgers (0.94) SMZ-867 × *nor*-RM-1 (0.89) PAU 114 ×*alc*-IIHR-2050 (0.89) Malintka ×*alc*-IIHR-2050 (0.88)	Spectrum × *nor*-RM-1 (80.00**) FL-556 × *nor*-RM-1 (75.56**) LST-17 × *nor*-RM-1 (75.56**) Roma × *alc*-IIHR-2050 (52.73**) Roma × *nor*-RM-1 (48.89*)	Leader × *rin*-Rutgers (80.77**) SMZ-867 × *nor*-RM-1 (71.15**) PAU 114 × *alc*-IIHR-2050(71.15**) Malintka × *alc*-IIHR-2050 (69.23**) Roma × *alc*-IIHR-2050 (61.54**)

CONCLUSION

Ripening mutants such as rin, nor, alc, Nr, Cnr and Gr which interfere the ripening process of tomato found beneficial for extending fruit availability period up to the end of spring season through hybrid development. Evaluation of crosses gives an opportunity of selecting supreme heterotic hybrids showing maximum harvesting span. From overall analysis, it was concluded that the F1 combinations viz. PAU 2381 × nor-RM-1, LT-44 × rin-Rutgers, Leader × nor-RM-1, LT-42 × alc-IIHR-2050, CLN1621L × alc-IIHR-2050 and Roma × nor-RM-1 in main (E_1) season (Supplementary Table 1) while crosses, PAU 2381 × rin-Rutgers, FL-556 × rin-Rutgers, FL-556 × alc-IIHR-2050, LT-44 × rin-Rutgers, LT-44 × alc-IIHR-2050 and CLN1621L × alc-IIHR-2050 in spring (E_2) season (Supplementary Table 2) were recorded for prolonged harvesting span vis-à-vis desirable quality characters i.e. total fruit yield, average fruit weight, minimum days from transplanting to first harvest, pericarp thickness, titratable acidity, lycopene contet and dry matter with permissible amount of heterosis. Henceforth, the hybrid crosses which possessed maximum harvesting span along with good yield potential and superior quality traits performance can be exploited for commercial purpose.

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