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Determination of S alleles in Paviot × Levent apricot progenies by PCR and controlled pollination

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Summary

In this study, the sexual incompatibility of Paviot and Levent apricot parents and 89 F_1 (Paviot × Levent) progenies was determined by self-pollination experiments and S-allele-specific polymerase chain reaction (PCR) technique. According to the self-pollination and isolation analyses under field conditions, it was found that the Paviot genotype is self-compatible (SC), whereas the Levent genotype is self-incompatible (SI). It was determined that, of all the progenies, 55 had a fruit set below 5% and were self-incompatible, whereas 34 had a fruit set over 5% and were self-compatible. The PCR-based techniques showed that, in parallel to the data obtained from the field studies, 55 F_1 progenies did not have S_c allele, whereas 34 progenies involved S_c allele. There were S_cS_2 alleles in the Paviot genotype and $S_{20}S_{52}$ alleles in the Levent genotype. It was determined that there were S_2S_{20}, S_2S_{52}, S_cS_{20}, and S_cS_{52} alleles in 89 F_1 progenies and the distribution of the four alleles in the progenies was found to be as follows: 35.9% S_2S_{20}, 25.8% S_2S_{52}, 23.6% S_cS_{20}, and 14.6% S_cS_{52}. F_1 progenies nos. 41, 46, 86, and 89 should be used as pollinators in further breeding studies.

Keywords: Apricot, Paviot, Levent, Self-incompatibility, PCR

Introduction

Apricot is one of the most important fruit types grown under mild temperature conditions in the world. It is a delicious fruit owing to its strong flavor and sugar-organic acid balance (Gurrieri et al., 2001). Some European and Mediterranean countries such as Turkey, Spain, Italy, France, and Greece have many local types of apricots, and these countries contribute to more than 75% of the total apricot production in the world (Leccese et al., 2010).

Apricot belongs to *Prunus* species of the Rosaceae family (Ozbek, 1978). It was reported that there are two genes that control the gametophytic self-incompatibility in *Prunus* species. One of these genes is S-ribonuclease (S-RNase) related to the stylus and the other one is the S-haplotype-specific F-box protein gene (SFB) related to pollen (Kao and Tsukamoto, 2004; Qiao et al., 2004; McClure, 2006).

Similar to the incompatibility, the functional capability of pollen is ascribed by a series of genes (S_1, S_2, S_3, S_4, … ,S_n [multiple allele series]). The diploid stylus typically involves two different S genes, and each pollen grain carries one of the two genes. These gene regions code S-RNase protein, which makes the incompatible species to reject their own pollen (Ebert et al., 1986; McClure et al., 1989). The glycoproteins that have this ribonuclease activity define S specificity in the pistil. If the pistil has the same gene as that of the pollen, S-RNase shows a cytotoxic effect on the pollen tubes and prevents the growth of the tubes, which leads to incompatibility (Roalson and McCubin, 2003; Goldraij et al., 2006). In this case, either the tip of the pollen tube that progresses through the stylus swells or the tube end explodes (Heslop-Harrison, 1975). Some physiological studies indicated that RNA degrades within 12-45 h followed by an incompatible pollination (McClure et al., 1990).

The breeding experiments are divided into the following two main groups: conventional and biotechnological. The biotechnological breeding includes molecular marker-assisted selection and genetic transformation methods. This breeding yields the results more rapidly than the conventional one (Bassi, 2006). In the apricot species obtained from North America and Spain, initially, seven S alleles ($S_{1\text{-}7}$) were defined by using molecular techniques (Alburquerque et al., 2002). Later, nine more alleles ($S_{8\text{-}16}$) were defined through NEpHGE and polymerase chain reaction (PCR) methods (Halasz et al., 2005). The existing S alleles were then detected in the apricot species obtained from China, North America, Europe, Turkey, and Tunisia (Egea and Burgos, 1996; Halasz et al., 2005; Zhang et al., 2008; Milatovic et al., 2010; Halasz et al., 2010; Lachkar et al., 2013).

The main objective of all breeding experiments is to improve productivity. The productivity depends on the factors such as environmental adaptability and self-incompatibility. Most of the self-incompatible apricot varieties cannot be used in breeding programs as they result in irregular fruit set and require a pollinator (Zhebentyayeva et al., 2012). Therefore, it is very important to know the incompatibility among the species that are used as parents in breeding experiments. Sexual incompatibility can be found in many commercially cultivated fruit species. In order to ensure the fruit set in these species, there is a necessity for cross-pollination by the wind or insects and pollinator species (Badanes et al., 2000). The present study aimed to determine the sexual incompatibility and to reveal the heredity of sexual incompatibility in 89 F_1 (Paviot × Levent) progenies by the field and laboratory experiments.

Materials and methods

Plant Material

The research materials were obtained from the Apricot Collection Orchard affiliated to İnönü University. This area has a continental climate with latitude: altitude 977 m, 38°20'20.23 N and longitude 38°26'26.56 E. In this study, 89 F_1 progenies (Paviot × Levent) were used. F_1 progenies were obtained through the artificial pollination performed under the scope of the TUBITAK-TOGTAG Project in 2003. The hybridization was carried out to obtain the progenies having the desired characteristics such as Paviot's big fruits, orange color of fruit peel, and resistance against Plum Pox: Levent's late blooming features. The leaf samples of each plant were stored at 4 °C after lyophilization. Fruit yield was determined as the mean fruit quantity of per apricot tree (kg/tree). For each genotype, weighting was done for every 10 fruits using a 0.05-g digital balance. The Brix° degree of the fruit juice from 10 fruits was determined by digital refractometry (Asma and Ozturk, 2005).

Pollination tests

In the pollination tests, conducted during 2009-2011, from each progeny, three different branches, each of which having approxi-

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mately 300 flowers, were selected. The first branch was labeled and left to open pollination. The second branch was bagged using double-layered cheese cloth to prevent cross-pollination and to ensure self-pollination a week before the anthesis. The third branch was emasculated and left open, after that, they were artificially pollinated for two or three times with their own pollen, which had been collected and dried a day before. Approximately after 70-80 days, the fruit set rates were determined. At the end of the isolation and artificial pollination, the progenies having the fruit set less than 5% were evaluated to be self-incompatible, and the others having more than 5% were considered self-compatible (FAUST, 1998).

DNA extraction, S allele PCR analysis, and DNA sequencing

For DNA isolation from the leaf samples, the CTAB (Cetyl Trimethyl Ammonium Bromide) protocol developed by DOYLE and DOYLE (1987) was used with minor modifications (KAFKAS and PERL-TREVES, 2001). The concentration of DNA in the samples was determined by comparing with λ-DNA that was quantified by the gel electrophoresis.

To determine S alleles, PCR was conducted using the primer combinations designed for the first and second introns of S-RNase genes and developed by TAO et al. (1999), ROMERO et al. (2004) and VILANOVA et al. (2005) as listed in Tab. 1.

Each PCR reaction in 25 µL contained 75 mM Tris-HCl (pH 8.8), 20 mM $(NH_4)_2SO_4$, 2 mM $MgCl_2$, 0.1% Tween 20, 100 µM dATP, 100 µM dTTP, 100 µM dGTP, 100 µM dCTP, 0.2 µM of each primer, 1.0 unit of Taq DNA polymerase, and 50 ng of DNA. For PCR amplification, the samples were pre-denatured at 94 °C for 3 min, followed by 35 cycles with denaturation for 45 s at 94 °C, annealing for 45 s at 54 °C or 58 °C, and extension for 60 s at 72 °C. For the final extension step, the samples were kept at 72 °C for 10 min. The PCR products were separated by electrophoresis on a 2% or 3% agarose gel with 0.5× TBE (Tris-Borate-EDTA) depending on the band size and were visualized under UV light by staining after with ethidium bromide. At the same time, the amplification products were analyzed by capillary electrophoresis using an ABI prism 3130xl automatic DNA sequencer (Applied Biosystems).

The DNA sequencing of the PCR products was commercially performed following Sanger's method at Medsantek, Istanbul, Turkey. The S alleles of the parents were determined by comparing the sequences using BLAST with those available at the National Center for Biotechnology Information (NCBI) database.

Tab. 1: Primers used to determine S-alleles of genotypes

Primers	Primer Design	Base number	Reference
SRc-R	GGC CAT TGT TGC ACA AAT TG	20	Vilanova et al., 2005
SRc-F	CTC GCT TTC CTT GTT CTT GC	20	Romero et al., 2004
PruT2F	GTT CTT GCT TTT GCT TTC TTC	21	Tao et al., 1999
PruC4R	GGA TGT GGT ACG ATT GAA GCG	21	Tao et al., 1999
PruC2F	CTT TGG CCA AGT AAT TAT TCA AAC	24	Tao et al., 1999

Statistical analysis

The data are presented as means ($n = 3$) ±standard deviations (s.d.). All statistical analyses were performed using SPSS 15.0 software. DUNCAN's test (1955) was used for the significance control ($p < 0.05$) following variance analysis (ANOVA).

Results and discussion

Pollination Tests

The fruit set was 70% for the Paviot genotype and 45% for the Levent genotype left open to the pollination. The fruit set of 51% was observed in the Paviot genotype, and no fruit set was found for the Levent genotype left to closed pollination during the harvest period in 2009. Similarly, in the self-pollination branches, the fruit set rate was detected to be 52% in the Paviot genotype and 1.5% in the Levent genotype. In the isolation and self-pollination experiments, the fruit set rate in the 56 F_1 genotypes was below 5% (Tab. 2). FAUST (1998) suggested that the verities having a fruit set rate less than 5%, where self-pollination has been conducted, can be defined as self-incompatible, whereas those having a fruit set more than 5% can be defined as self-compatible. ASMA (2008) conducted the isolation and self-pollination experiments and reported that the fruit set rate of the Levent apricot genotype was below 5% and this genotype was self-incompatible. Thus considering the results of our study, it can be affirmed that Paviot genotype is self-compatible and the Levent genotype is self-incompatible; 55 F_1 progenies are self-incompatible while 34 are self-compatible (Tab. 2). Similar results were obtained from the field studies of different cultivars in recent years. ASKIN (1989) reported that fruit set in Tokaloglu and Sam apricot cultivars that do not yield fruit regularly in the Aegean Region was 0.46% and 0.65%, respectively, and these species were self-incompatible. BOLAT and GULERYUZ (1994) reported that the fruit set rate was higher in the case of cross-pollination than self-pollination in Hasanbey cultivars. PAYDAS et al. (2001) determined that 25 of the 62 apricot cultivars cultivated in the Malatya province were self-compatible, while GULCAN et al. (2006) determined that 32 of the 70 apricot genotypes cultivated in Adana and Malatya provinces were self-compatible. According to self-pollination studies conducted on Katy, Harcot, and Jiguang hybrids by WU et al. (2011), fruit set rates were determined to be as follows: 19.68% for Katy × Harcot, 15.45% for Harcot × Katy, 7.78% for Katy × Jiguang, and 16.75% for Jiguang × Katy. In self-pollination studies of Harcot and Chuanzhihong cultivars, fruit set rates were 0.57% and 0%; these rates were 11.29% and 22.87% in cross-pollination experiments (Harcot × Chuanzhihong and Chuanzhihong × Harcot), and both cultivars were reported to be self-incompatible (GU et al., 2013).

S allele PCR analyses and DNA sequencing

At the end of PCR studies conducted with the PruT2, Src-F, and Src-R primer combinations for the amplification of the first intron region of the apricot S-RNase, a band of 353-bp was found in the Paviot genotype (Fig. 1). In previous studies, the cultivars that showed the 353-bp band were reported to be self-compatible when this primer combination was used (VILANOVA et al., 2005). In addition, a band of 328-bp in the Paviot genotype and 420-bp in the Levent genotype were found.

In the PCR experiment, conducted with PruC2F and PruC4R primer combination for the amplification of the second intron region of S-RNase, no band was amplified for the Paviot genotype, and two bands of approximately 1400 and 2100 bp were detected for the Levent genotype. The analysis of the alleles included in F_1 genotypes showed that the 420-bp band in the gel obtained through PruT2-SrcF-SrcR combination in the Levent genotype was the same to the 1400-bp band found in PruC2F-C4R combination.

The comparison of the nucleotide sequence obtained from the SrcF-SrcR primer combination in parents and the current apricot S allele sequences in the NCBI database indicated that S allele sequences of

Tab. 2: Mean comparison of fruit set percentage after open, isolated and self-pollination in F_1 progenies

Progenies	Open Pollination (%)	Isolated Pollination (%)	Self Pollination (%)	Progenies	Open Pollination (%)	Isolated Pollination (%)	Self Pollination (%)
Paviot	70^{a}	51^{a}	52^{a}	**P×L 45**	16.9^{d}	0.9^{d}	2.5^{cd}
Levent	45^{bc}	0	0	**P×L 46**	24.2^{cd}	40.5^{ab}	34.6^{b}
P×L 01	30^{cd}	0	0	**P×L 47**	47.5^{b}	10.4^{c}	10.9^{c}
P×L 02	25^{cd}	12.2^{c}	25.3^{b}	**P×L 48**	28.5^{cd}	20^{bc}	40.2^{ab}
P×L 03	52.7^{b}	1.2^{d}	0	**P×L 49**	15.5^{d}	0	3.2^{cd}
P×L 04	50^{b}	1.1^{d}	0	**P×L 50**	17.4^{d}	0	1.2^{d}
P×L 05	27.1^{cd}	0	0	**P×L 51**	38.5^{bc}	6.3^{cd}	14.6^{bc}
P×L 06	30.7^{cd}	23^{bc}	17^{bc}	**P×L 52**	26.5^{cd}	16^{bc}	16.1^{bc}
P×L 07	20^{cd}	0	0	**P×L 53**	32.1^{c}	6^{cd}	1^{d}
P×L 08	38^{c}	3^{cd}	2^{d}	**P×L 54**	52.2^{b}	0	4.1^{cd}
P×L 09	45^{bc}	0	2^{d}	**P×L 55**	25^{cd}	12.3^{c}	10.8^{cv}
P×L 10	13.9^{d}	20^{bc}	30^{b}	**P×L 56**	15.9^{d}	0	0
P×L 11	25^{cd}	25.9^{b}	19.1^{bc}	**P×L 57**	39.6^{bc}	12^{c}	19.7^{bc}
P×L 12	36.9^{c}	0	1.5^{d}	**P×L 58**	15.4^{d}	14.2^{bc}	40.6^{ab}
P×L 13	46.7^{bc}	45^{ab}	29.1^{b}	**P×L 59**	15^{d}	1^{d}	0
P×L 14	41.6^{bc}	15.2^{bc}	35^{ab}	**P×L 60**	21^{cd}	0	0
P×L 15	34.5^{c}	2.3^{cd}	0	**P×L 61**	20.1^{cd}	0	0
P×L 16	59.5^{ab}	16.7^{bc}	46.5^{ab}	**P×L 62**	14.5^{d}	6.7^{cd}	4.9^{cd}
P×L 17	30.4^{cd}	2.7^{cd}	1.6^{d}	**P×L 63**	11^{d}	5.8^{cd}	5^{cd}
P×L 18	7.4^{de}	1.9^{d}	0	**P×L 64**	11.8^{d}	0	0
P×L 19	13.3^{d}	17.5^{bc}	24.4^{b}	**P×L 65**	14.1^{d}	15.2^{bc}	14.3^{bc}
P×L 20	37.1^{c}	1.3^{d}	0	**P×L 66**	28.9^{cd}	0	0
P×L 21	31.4^{cd}	0	0	**P×L 67**	21.6^{cd}	0	0
P×L 22	26.7^{cd}	1.5^{d}	1.4^{d}	**P×L 68**	11^{d}	0	0
P×L 23	30^{cd}	1.5^{d}	0	**P×L 69**	17.6^{d}	0	0
P×L 24	42.6^{bc}	6.9^{cd}	17.5^{bc}	**P×L 70**	13.4^{d}	5^{cd}	6.7^{cd}
P×L 25	21.3^{cd}	16.7^{bc}	10^{c}	**P×L 71**	17.1^{d}	6.2^{cd}	6.4^{cd}
P×L 26	10.7^{d}	16^{bc}	14.7^{bc}	**P×L 72**	13.2^{d}	0	0
P×L 27	20.8^{cd}	13.8^{c}	20.5^{bc}	**P×L 73**	9.9d^{e}	0	2.2^{cd}
P×L 28	50.6^{b}	12.9^{c}	16.5^{bc}	**P×L 74**	11.3^{d}	1^{d}	0
P×L 29	11.3^{d}	0	1.1^{d}	**P×L 75**	10.9^{d}	0	0
P×L 30	11.9^{d}	3.2^{cd}	1.7^{d}	**P×L 76**	7d^{e}	0	0
P×L 31	25^{cd}	0	0	**P×L 77**	8.9^{de}	0	0
P×L 32	22^{cd}	0	1^{d}	**P×L 78**	12.1^{d}	7.6^{c}	6.5^{cd}
P×L 33	29.1^{cd}	0	1.7^{d}	**P×L 79**	9.1^{de}	0	3^{cd}
P×L 34	16.4^{d}	5.8^{cd}	6.7^{cd}	**P×L 80**	11.4^{d}	1^{d}	1^{d}
P×L 35	50^{b}	0	0	**P×L 81**	15^{d}	0	1^{d}
P×L 36	15.5^{d}	0	0	**P×L 82**	9.9^{de}	7.2^{c}	6.6^{cd}
P×L 37	15.6^{d}	9.4^{c}	20.9^{bc}	**P×L 83**	10.1^{d}	0	0
P×L 38	34.7^{c}	0	0	**P×L 84**	12.5^{d}	0	0
P×L 39	10.9^{d}	4.7^{cd}	4.4^{cd}	**P×L 85**	15.9^{d}	0	0
P×L 40	36.2^{bc}	20.5^{bc}	19.9^{bc}	**P×L 86**	19.8^{cd}	4.5^{cd}	5.7^{cd}
P×L 41	54.3^{b}	46.3^{ab}	34.2^{b}	**P×L 87**	5.7^{e}	0	0
P×L 42	41.7^{bc}	0	0	**P×L 88**	12.3^{d}	0	0
P×L 43	17.8^{d}	1.1^{d}	0	**P×L 89**	9.1^{de}	7.2^{c}	6.9^{cd}
P×L 44	34^{c}	12.9^{c}	11.8^{c}				

Data followed by different letters are significantly different from each other ($P < 0.05$) according to Duncan's test.

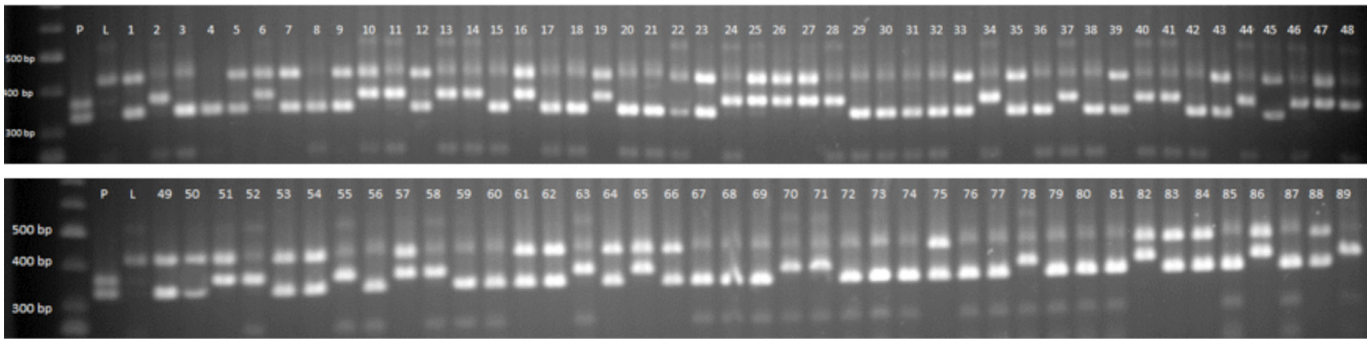

Fig. 1: S alleles determined through the use of Pru T2, SrcF and SrcR primer combination in parents and F_1 progenies

Paviot and Levent genotypes show homology with the S_c (353 bp), S_2 (328 bp), S_{52} (1400 bp), and S_{20} (2100 bp) allele sequences of *Prunus armeniaca* available at GenBank (ROMERO et al., 2004; VILANOVA et al., 2006; ZHANG et al., 2008; JIANG et al., 2010). HALASZ et al. (2010) reported that there are S_6S_{19} alleles in the Levent genotype so this apricot genotype is self-incompatible. In the present study, the PCR bands obtained for the Levent genotype were sequenced bidirectionally using the primers designed with the first and second intron regions and the obtained DNA sequences were compared with the allele sequences available in GenBank. At the end of this study, the presence of $S_{20}S_{52}$ allele was found in the Levent genotype. Similarly, YILMAZ et al. (2013) reported that there was no S_c allele in the Levent genotype and this genotype was self-incompatible. In a study conducted with 63 wild apricot genotypes in Erzincan, it was reported that the local apricot cultivars cultivated in the eastern region of Turkey mostly do not carry S_c allele (HALASZ et al., 2013).

In parallel with the results obtained under field conditions, it was found that 55 of the 89 F_1 progenies did not carry the S_c allele, and these progenies were self-incompatible (Tab. 3). It was found that 55 F_1 progenies carried S_2S_{52} and S_2S_{20} allele pairs, and these plants were self-incompatible. The distribution in F_1 progenies of the alleles detected in Paviot (S_cS_2) and Levent ($S_{20}S_{52}$) parents was as follows: 35.9% for S_2S_{20}, 25.8% for S_2S_{52}, 23.6% for S_cS_{20}, and 14.6% for S_cS_{52}. BURGOS et al. (1997) reported that self-compatibility alleles are dominant over incompatible alleles. In the present study, one

Tab. 3: S genotypes of Paviot × Levent F_1 progenies

Progenies	Alleles	Progenies	Alleles	Progenies	Alleles	Progenies	Alleles
Paviot	S_cS_2	**P×L 22**	S_2S_{20}	**P×L 45**	S_2S_{52}	**P×L 68**	S_2S_{20}
Levent	$S_{20}S_{52}$	**P×L 23**	S_2S_{52}	**P×L 46**	S_cS_{20}	**P×L 69**	S_2S_{20}
P×L 01	S_2S_{52}	**P×L 24**	S_cS_{20}	**P×L 47**	S_cS_{52}	**P×L 70**	S_cS_{20}
P×L 02	S_cS_{20}	**P×L 25**	S_cS_{52}	**P×L 48**	S_cS_{20}	**P×L 71**	S_cS_{20}
P×L 03	S_2S_{20}	**P×L 26**	S_cS_{52}	**P×L 49**	S_2S_{52}	**P×L 72**	S_2S_{20}
P×L 04	S_2S_{20}	**P×L 27**	S_cS_{52}	**P×L 50**	S_2S_{52}	**P×L 73**	S_2S_{20}
P×L 05	S_2S_{52}	**P×L 28**	S_cS_{20}	**P×L 51**	S_cS_{52}	**P×L 74**	S_2S_{20}
P×L 06	S_cS_{52}	**P×L 29**	S_2S_{20}	**P×L 52**	S_cS_{20}	**P×L 75**	S_2S_{52}
P×L 07	S_2S_{52}	**P×L 30**	S_2S_{20}	**P×L 53**	S_2S_{52}	**P×L 76**	S_2S_{20}
P×L 08	S_2S_{20}	**P×L 31**	S_2S_{20}	**P×L 54**	S_2S_{52}	**P×L 77**	S_2S_{20}
P×L 09	S_2S_{52}	**P×L 32**	S_2S_{20}	**P×L 55**	S_cS_{20}	**P×L 78**	S_cS_{20}
P×L 10	S_cS_{52}	**P×L 33**	S_2S_{52}	**P×L 56**	S_2S_{20}	**P×L 79**	S_2S_{20}
P×L 11	S_cS_{20}	**P×L 34**	S_cS_{20}	**P×L 57**	S_cS_{52}	**P×L 80**	S_2S_{20}
P×L 12	S_2S_{52}	**P×L 35**	S_2S_{52}	**P×L 58**	S_cS_{20}	**P×L 81**	S_2S_{20}
P×L 13	S_cS_{20}	**P×L 36**	S_2S_{20}	**P×L 59**	S_2S_{20}	**P×L 82**	S_cS_{52}
P×L 14	S_cS_{20}	**P×L 37**	S_cS_{20}	**P×L 60**	S_2S_{20}	**P×L 83**	S_2S_{52}
P×L 15	S_2S_{20}	**P×L 38**	S_2S_{20}	**P×L 61**	S_2S_{52}	**P×L 84**	S_2S_{52}
P×L 16	S_cS_{52}	**P×L 39**	S_2S_{52}	**P×L 62**	S_2S_{52}	**P×L 85**	S_2S_{20}
P×L 17	S_2S_{20}	**P×L 40**	S_cS_{20}	**P×L 63**	S_cS_{20}	**P×L 86**	S_cS_{52}
P×L 18	S_2S_{20}	**P×L 41**	S_cS_{20}	**P×L 64**	S_2S_{52}	**P×L 87**	S_2S_{20}
P×L 19	S_cS_{52}	**P×L 42**	S_2S_{20}	**P×L 65**	S_cS_{52}	**P×L 88**	S_2S_{52}
P×L 20	S_2S_{20}	**P×L 43**	S_2S_{52}	**P×L 66**	S_2S_{52}	**P×L 89**	S_cS_{20}
P×L 21	S_2S_{20}	**P×L 44**	S_cS_{20}	**P×L 67**	S_2S_{20}		

Tab. 4: Fruit characteristics of F_1 genotypes

Pro-genies	Fruit Weight (g)	Kernel Weight (g)	Brix° (%)	Pro-genies	Fruit Weight (g)	Kernel Weight (g)	Brix° (%)	Pro-genies	Fruit Weight (g)	Kernel Weight (g)	Brix° (%)
P×L 01	27.6± 2.5^{c}	3.1± 0.2^{b}	16.0± 1.1^{b}	**P×L 31**	31.6± 2.4^{bc}	3.3± 0.2^{b}	18.0± 1.0^{a}	**P×L 61**	24.9± 3.1^{c}	3.3± 0.2^{b}	18.5± 1.2^{ab}
P×L 02*	23.1± 2.2^{c}	2.6± 0.2^{b}	16.0± 1.0^{b}	**P×L 32**	18.2± 1.9^{d}	2.4± 0.2^{b}	16.0± 1.4^{b}	**P×L 62***	24.9± 3.1^{c}	3.3± 0.2^{b}	18.5± 1.2^{ab}
P×L 03*	24.0± 2.8^{c}	2.2± 0.2^{b}	18.0± 0.9^{ab}	**P×L 33**	33.5± 2.4^{bc}	3.5± 0.3^{b}	17.0± 1.0^{b}	**P×L 63***	29.9± 2.5^{bc}	2.8± 0.2^{b}	14.0± 0.5^{c}
P×L 04	30.2± 2.3^{bc}	4.3± 0.3^{a}	18.0± 0.6^{ab}	**P×L 34***	39.4± 2.7^{b}	3.4± 0.2^{b}	18.0± 1.2^{ab}	**P×L 64**	22.9± 2.0^{c}	2.7± 0.2^{b}	23.0± 1.2^{a}
P×L 05	44.2± 4.5^{b}	3.3± 0.3^{b}	19.0± 1.2^{a}	**P×L 35**	31.5± 2.8^{bc}	3.0± 0.3^{b}	18.0± 1.4^{ab}	**P×L 65**	35.7± 2.9^{bc}	4.1± 0.3^{a}	20.0± 1.5^{a}
P×L 06	20.0± 2.0^{c}	2.7± 0.2^{b}	18.0± 1.5^{ab}	**P×L 36**	28.3± 2.1^{c}	3.0± 0.2^{b}	18.0± 1.1^{ab}	**P×L 66**	26.9± 2.2^{c}	2.9±0.3^{b}	19.0± 1.3^{a}
P×L 07	18.8± 1.6^{d}	3.4± 0.3^{b}	18.0± 1.2^{ab}	**P×L 37**	44.9± 2.8^{b}	4.1± 0.3^{a}	21.0± 0.8^{a}	**P×L 67**	34.5± 2.5^{bc}	3.2± 0.3^{b}	15.0± 1.1^{b}
P×L 08	25.4± 2.3^{c}	3.1± 0.2^{b}	21.0± 1.1^{a}	**P×L 38**	35.8± 2.2^{bc}	3.5± 0.2^{b}	20.0± 0.6^{a}	**P×L 68***	24.9± 2.6^{c}	2.8±0.4^{b}	16.0± 1.1^{b}
P×L 09	24.8± 2.1^{c}	2.5± 0.3^{b}	19.0± 1.3^{a}	**P×L 39**	32.7± 2.1^{bc}	3.7± 0.2^{ab}	19.0± 0.9^{a}	**P×L 69***	18.1± 1.8^{d}	2.4±0.6^{b}	12.0± 1.0^{d}
P×L 10	20.2± 2.0^{c}	2.4± 0.1^{b}	18.0± 1.1^{ab}	**P×L 40**	18.4± 1.9^{d}	2.6± 0.2^{b}	14.0± 0.5^{c}	**P×L 70**	39.3± 3.9^{bc}	3.8± 0.3^{ab}	21.0± 1.1^{a}
P×L 11	49.8± 3.7^{b}	3.4± 0.1^{b}	20.0± 1.4^{a}	**P×L 41****	51.8± 2.2^{ab}	4.3± 0.4^{a}	20.0± 0.8^{a}	**P×L 71**	40.1± 3.0^{b}	3.8± 0.3^{ab}	18.0± 1.0^{ab}
P×L 12	22.3± 2.5^{c}	2.1± 0.1^{b}	22.0± 1.2^{a}	**P×L 42**	40.6± 2.4^{b}	2.5± 0.1^{b}	19.0± 0.6^{a}	**P×L 72***	20.6± 1.5^{c}	2.3± 0.2^{b}	16.0± 1.0^{b}
P×L 13	21.5± 3.1^{c}	2.6± 0.1^{b}	14.0± 0.6^{c}	**P×L 43**	30.4± 2.1^{bc}	3.1± 0.2^{b}	13.0± 0.5^{c}	**P×L 73**	27.4± 2.6^{c}	2.8± 0.2^{b}	18.0± 1.1^{ab}
P×L 14	23.5± 2.4^{c}	2.1± 0.1^{b}	16.0± 0.7^{b}	**P×L 44**	39.4± 3.9^{b}	3.0± 0.2^{b}	19.0± 0.9^{a}	**P×L 74**	47.3± 3.8^{b}	4.3± 0.3^{a}	19.0± 1.0^{a}
P×L 15*	30.6± 2.8^{bc}	3.9± 0.3^{ab}	20.0± 1.3^{a}	**P×L 45**	36.9± 2.5^{bc}	3.1± 0.1^{b}	20.0± 0.6^{a}	**P×L 75**	23.6± 2.5^{c}	2.7± 0.2^{b}	17.0± 1.4^{b}
P×L 16	18.1± 1.9^{d}	3.0± 0.2^{b}	21.0± 1.2^{a}	**P×L 46***	59.3± 4.8^{ab}	2.5± 0.2^{b}	18.0± 0.8^{ab}	**P×L 76**	33.6± 3.7^{bc}	3.4± 0.3^{b}	17.0± 1.5^{b}
P×L 17**	33.5± 2.5^{bc}	3.8± 0.3^{ab}	22.0± 1.4^{a}	**P×L 47**	27.8± 2.9^{c}	3.2± 0.2^{b}	18.0± 0.5^{ab}	**P×L 77**	25.7± 2.5^{c}	2.1± 0.2^{b}	15.0± 1.3^{b}
P×L 18*	31.1± 2.3^{bc}	3.2± 0.2^{b}	17.0± 1.4^{b}	**P×L 48**	70.5± 4.7^{a}	4.6± 0.3^{a}	14.0± 0.6^{c}	**P×L 78**	21.2± 2.6^{c}	2.6± 0.2^{b}	16.0± 0.8^{b}
P×L 19	42.6± 3.6^{b}	3.7± 0.2^{ab}	22.0± 1.2^{a}	**P×L 49**	32.9± 2.5^{bc}	3.7± 0.2^{ab}	16.5± 0.8^{bc}	**P×L 79**	23.6± 2.2^{c}	2.8± 0.2^{b}	18.0± 0.6^{ab}
P×L 20*	30.5± 2.9^{bc}	3.5± 0.2^{b}	19.0± 1.1^{a}	**P×L 50**	31.4± 2.2^{bc}	3.2± 0.2^{b}	19.0± 1.5^{a}	**P×L 80**	34.8± 2.1^{bc}	3.0± 0.2^{b}	17.5± 0.9^{ab}
P×L 21*	34.8± 2.4^{bc}	3.4± 0.2^{b}	22.0± 1.0^{a}	**P×L 51***	21.6± 2.1^{c}	2.9± 0.2^{b}	16.0± 0.6^{b}	**P×L 81**	45.6± 4.9^{b}	4.3± 0.3^{a}	18.0± 1.0^{ab}
P×L 22*	22.2± 2.1^{c}	2.5± 0.1^{b}	19.0± 1.5^{a}	**P×L 52***	23.5± 2.9^{c}	3.4± 0.2^{b}	17.0± 0.5^{b}	**P×L 82**	30.6± 2.8^{bc}	2.5± 0.1^{b}	16.0± 1.2^{b}
P×L 23*	14.6± 1.9^{d}	1.6± 0.1^{c}	20.0± 1.5^{a}	**P×L 53***	40.3± 2.1^{b}	3.4± 0.3^{b}	22.0± 0.9^{a}	**P×L 83***	65.0± 5.5^{a}	4.6± 0.3^{a}	14.0± 1.2^{c}
P×L 24	35.7± 2.5^{bc}	3.9± 0.2^{ab}	17.5± 1.1^{ab}	**P×L 54***	19.0± 1.4^{d}	2.1± 0.1^{b}	19.0± 0.9^{a}	**P×L 84**	59.0± 4.9^{ab}	4.4± 0.3^{a}	19.0± 1.1^{a}
P×L 25	29.4± 1.4^{bc}	2.7± 0.2^{b}	18.0± 1.4^{ab}	**P×L 55**	24.1± 1.6^{c}	2.1± 0.1^{b}	17.0± 0.5^{b}	**P×L 85**	37.0± 2.5^{bc}	3.4± 0.2^{b}	16.0± 1.0^{b}
P×L 26	40.3± 3.8^{b}	3.9± 0.2^{ab}	17.0± 1.6^{b}	**P×L 56***	48.2± 1.5^{b}	3.0± 0.1^{b}	20.0± 1.1^{a}	**P×L 86***	62.0± 5.5^{a}	4.5± 0.3^{a}	20.0± 1.2^{a}
P×L 27	32.9± 2.3^{bc}	2.9± 0.2^{b}	17.0± 1.2^{b}	**P×L 57**	46.3± 3.6^{b}	3.9± 0.1^{ab}	19.0± 1.0^{a}	**P×L 87**	43.0± 5.2^{b}	3.8± 0.2^{ab}	15.0± 0.8^{b}
P×L 28	38.1± 3.6^{bc}	3.9± 0.2^{ab}	19.0± 1.5^{a}	**P×L 58**	34.0± 3.2^{bc}	3.3± 0.3^{b}	15.0± 1.4^{b}	**P×L 88**	33.3± 2.6^{bc}	3.3± 0.2^{b}	16.0± 0.7^{b}
P×L 29	18.1± 1.8^{d}	2.2± 0.2^{b}	21.0± 1.5^{a}	**P×L 59**	31.6± 3.5^{bc}	3.0± 0.3^{b}	16.5± 1.2^{b}	**P×L 89****	55.7± 4.5^{ab}	4.2± 0.3^{a}	19.0± 1.8^{a}
P×L 30	39.1± 2.6^{b}	4.1± 0.3^{a}	23.0± 1.6^{a}	**P×L 60**	23.8± 3.2^{c}	2.2± 0.1^{b}	20.0± 1.5^{a}				

*: High yield; **: Very high yield

Values are means ± standard deviation (SD) of three replications. Data followed by different letters are significantly different from each other ($P < 0.05$) according to Duncan's test.

incompatible allele and one S_c allele were found in 34 F_1 progenies, but they were self-compatible; in other words, S_c allele was found dominant over the incompatible allele.

Tab. 4 shows the pomological features of F_1 progenies observed in 2011. F_1 progenies nos. 2, 3, 15, 17, 18, 20, 21, 22, 23, 34, 41, 46, 51, 52, 53, 54, 56, 62, 63, 68, 69, 72, 83, 86, and 89 had high fruit yield. But the fruit weight and the total soluble solid content of some of these progenies were low. The genotypes that can be used in breeding experiments should be self-compatible and have good pomological properties. F_1 progenies nos. 41, 46, 86, and 89 had both high fruit yield, fruit weight, and total soluble solid content and they were also found to be self-compatible. The F_1 progeny no. 84 was self-incompatible although the quality was high in pomological characters.

Conclusion

The sexual incompatibility of Paviot and Levent apricot parents and 89 F_1 (Paviot × Levent) progenies was determined by self-pollination studies and S-allele-specific polymerase chain reaction (PCR). The fruit set rate was high as cross-pollination was allowed in the branches left open to pollination. No fruit set was found due to the incompatible fertilization in the isolated and self-pollinated branches in some progenies. Of the progenies, 55 were determined to be self-incompatible. In conclusion, it is recommended that F_1 progeny nos. 41, 46, 86, and 89 should be used as pollinators in further breeding experiments, as these progenies have high quality in pomological terms and they are self-compatible. The obtained results will be useful in the selection of parents in apricot breeding studies and these results will be useful for the selection of genotype in new apricot orchards.

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