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Article

Characterization of gynodioecious Pune selection lines of papaya

Sunil Kumar Sharma*, Savarni Tripathi

ICAR-Indian Agricultural Research Institute, Regional Station, Pune 411007, India
*** Corresponding author:** Sunil Kumar Sharma, sunilksharma1959@yahoo.co.in

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Abstract: Among major global threats to papaya cultivation, papaya ringspot virus (PRSV) is the most challenging one. In the absence of any PRSV resistant commercial papaya cultivar, PRSV management is restricted to minimizing yield losses. ICAR-Indian Agricultural Research Institute, Regional Station, Pune has developed PRSV tolerant dioecious papaya lines, Pune Selection (PS)-1, PS-2, PS-3 and PS-5. Being dioecious these lines have limited acceptability among farmers. Gynodioecious population from these lines were developed and characterized. They are numbered PS-1-1, PS-2-1, PS-3-1 and PS-5-1. These lines were characterized against prevailing commercial gynodioecious cultivar, Red Lady, for five generations. The average plant height of PS-2-1 and PS-5-1 (183 cm) was more than Red Lady (158 cm), however, stem girth of all lines was lesser than Red Lady. The fruiting height of all lines was less than Red Lady (87 cm). Length of the fruiting column of all lines was more than Red Lady (37 cm), except in PS-1-1. Fruit yield of all lines was more than Red Lady (16 kg/plant). Intensity of PRSV infection in Red Lady (48%) was considerably more than all lines. These lines can be used for developing PRSV tolerant gynodioecious papaya variety.

Keywords: *Carica papaya*; papaya ringspot virus (PRSV) tolerant gynodioecious lines; papaya germplasm

1. Introduction

Papaya (*Carica papaya* L.) is an important fruit crop which is cultivated in tropical and subtropical climate of Asia, Central America, and Africa. Global papaya production of 14.098 million tonnes of fresh fruits came from 486,161 hectare in 2021. Major papaya producing countries are India, Brazil, Nigeria, Indonesia and Mexico. Average global papaya yield was 29 tonnes/hectare while average yield of top four papaya producing countries was double of the global average [1,2]. Narrow gene pool of *C. papaya* (one species only) makes it vulnerable to many diseases [3–7]. Papaya production is unable to attain its potential due to its susceptibility to many diseases. Papaya ringspot virus (PRSV) infection is the most serious threat affecting worldwide papaya cultivation [8,9]. Neither PRSV infection can be prevented, nor can the infected plants be treated. Yield losses due to PRSV can be reduced up to a certain level by managing horticultural practices. Development of a PRSV resistant variety can offer a sustainable solution to the problem. Therefore, Prakash et al. [10] emphasized that the initial step of successful breeding programme will depend on selection of plants with tolerance/resistance against PRSV infection. Indian and exotic cultivars of papaya, and promising selections were screened for PRSV infection in Lucknow for using them in future breeding programme [11,12]. ICAR-Indian Agricultural Research Institute, Regional Station (IARI RS), Pune has developed PRSV tolerant dioecious lines, Pune Selection-1 (PS-1), PS-2, PS-3 and

PS-5 [13]. Being dioecious, these lines had unpredictable fruit production from uncertain number of fruits bearing female plants in the population. Therefore, gynodioecious populations of these lines have been developed into, PS-1-1, PS-2-1, PS-3-1 and PS-5-1. The Objective of the study was to document horticultural characterization including PRSV tolerance of these gynodioecious lines when compared with the prevailing gynodioecious popular commercial cultivar, Red Lady.

2. Materials and methods

The data was generated at IARI RS Pune (18°31'N, 73°51'E) for five consecutive production cycles from 2014–2015 to 2018–2019. Papaya can complete one production cycle in a year under the climatic conditions of Pune, India. As a prevailing practice, plants were uprooted after the end of every production cycle, and new plantation was undertaken. Fifty seedlings each of gynodioecious lines (PS-1-1, PS-2-1, PS-3-1 and PS-5-1) and Red Lady, as a check, were transplanted at a spacing of 1.8 m in rows 2.4 m apart. Data on growth, fruiting characters, fruit yield and intensity of PRSV infection was recorded. Plant height was measured from the ground level to the tip of the plant, stem girth was measured at the height of 15 cm from the ground, and fruiting height was measured from the ground to the first fruit. Fruit yield from the plant was measured by recording actual yield throughout the fruit production phase. PRSV intensity was measured at fruit setting stage by using the formula:

PRSV Intensity = [Total Score / (Total Number of Plants × Maximum Score)] × 100

The scorecard is given below. The method was developed by Datar et al. [14] and modified by Sharma and Tripathi [13]. The data collected using the above methodology was analyzed by using Microsoft Excel for Microsoft 365 MSO Version 2312. The average fruit weight was calculated by dividing total fruit yield by total number of fruits from a tree. The average value of all the fruit producing trees is presented here. Pulp thickness and TSS of five representative fruits was measured, and the average value is presented. Average data is presented along with the range and Standard Deviation.

PRSV scorecard [13]:

Disease score	Symptoms
00	No symptom
03	Appearance of one or two of the following systems: Mild mosaic/oily spot on petiole or stem/ringspot on fruits
05	Either all symptoms mentioned in score 03 or Appearance of one of the following systems: Blisters on leaf (A)/mild leaf reduction (B)/mild fruit deformation (C)
07	All symptoms in score 03 + A or B or C or Leaf distortion or Leaf margin burning or Shoestring formation in less than 10% foliage
09	All symptoms mentioned in score 03 + Shoestring formation in about more than 10% foliage, or Stunted growth or defoliation, or A + B + C + Shoestring formation, or A + B + C + Severe fruit deformation

3. Results and discussion

Plant height was variable among gynodioecious lines of Pune selections. It ranged from 121 cm to 203 cm in PS-1-1; 160 cm to 208 cm in PS-2-1; 126 cm to 174 cm in PS-3-1; and 140 cm to 218 cm in PS-5-1 during the study period of five production cycles from 2014–2015 to 2018–2019. The comparative data of all five cropping cycles revealed the maximum plant height in PS-5-1 (218 cm) in 2015-16 and the minimum in PS-1-1 (121 cm) in 2014-15 whereas variability in Red Lady ranged from 137 cm to 185 cm. The average of five production cycles showed the maximum plant height in PS-2-1 and PS-5-1 (183 cm) and minimum in PS-3-1 (149 cm), while that of Red Lady was 158 cm. The stem girth of all gynodioecious PS lines was lower than that of Red Lady. Variations in stem girth in Red Lady ranged from 34 cm (2014–2015) to 46 cm (2017–2018), while in gynodioecious lines it ranged from 29 cm to 36 cm in PS-1-1; from 32 cm to 44 cm in PS-2-1; from 29 cm to 42 cm in PS-3-1; and from 22 cm to 46 cm in PS-5-1. Considering the entire data, maximum stem girth was observed in PS-5-1 (46 cm) in 2017–2018 and minimum in PS-5-1 (22 cm) in 2014–2015 (**Table 1**).

Table 1. Plant height and stem girth during the study period in different papaya genotypes.

Year	Plant Height (cm)					Stem Girth (cm)				
	PS-1-1	**PS-2-1**	**PS-3-1**	**PS-5-1**	**Red Lady**	**PS-1-1**	**PS-2-1**	**PS-3-1**	**PS-5-1**	**Red Lady**
2014–15	121 (85–160) ± 17	169 (95–230) ± 33	126 (85–175) ±21	140 (90–170) ± 21	137 (100–165) ± 15	29 (10–37) ± 5	32 (17–48) ± 5	29 (11–37) ± 4	22 (12–34) ± 5	34 (26–41) ± 3
2015–16	203 (165–245) ± 28	208 (140–265) ± 33	174 (155–215) ± 16	218 (170–255) ± 28	185 (145–225) ± 18	36 (31–45) ± 4	41 (33–50) ± 6	37 (33–42) ± 3	42 (35–52) ± 5	43 (37–52) ± 4
2016–17	153 (125–185) ± 13	188 (150–220) ± 14	153 (130–175) ± 11	184 (125–240) ± 32	148 (110–170) ± 16	30 (22–38) ± 3	30 (22–38) ± 3	32 (25–41) ± 3	33 (21–46) ± 6	35 (28–43) ± 3
2017–18	-	191 (120–230) ± 25	163 (135–195) ± 18	202 (155–240) ± 26	175 (150–210) ± 14	-	44 (30–53) ± 5	42 (32–50) ± 4	46 (36–55) ± 5	46 (40–57) ± 3
2018–19	-	160 (115–190) ± 24	128 (110–190) ± 12	169 (110–265) ± 43	147 (115–180) ± 14	-	33 (21–39) ± 5	30 (27–35) ± 3	32 (13–45) ± 9	36 (32–42) ± 3
Average	159	183	149	183	158	32	36	34	35	39

[Average Value (Range) ± Standard Deviation].

Average value of fruiting height (based on all production cycles) was maximum in PS-1-1 and PS-2-1 (86 cm) and minimum in PS-3-1 (67 cm) while average fruiting height of Red Lady was 87 cm. Variations within Pune Selections were between 70 cm to 102 cm in PS-1-1; 73 cm to 112 cm in PS-2-1; 60 cm to 73 cm in PS-3-1; and 81 cm to 91 cm in PS-5-1. While variations in fruiting height in Red Lady ranged from 75 cm to 100 cm. Average length of fruiting column in PS-5-1 was maximum (59 cm) whereas the minimum fruiting column (37 cm) was recorded in PS-1-1. The fruiting column in Red Lady (44 cm) was lower than all Pune Selections except for PS-1-1. Data on fruiting column of individual crop cycle showed the maximum value in PS-2-1 (78 cm) in 2015–2016 and minimum in PS-1-1 (27 cm) in 2016–2017. Red Lady showed a range of 31 cm to 54 cm in the length of fruiting column. Whereas it varied in gynodioecious Pune Selections from 27 cm to 45 cm in PS-1-1; from 32 cm to 78 cm in PS-2-1; from 30 cm to 67 cm in PS-3-1;

and from 35 cm to 72 cm in PS-5-1 (**Table 2**).

Table 2. Fruiting height and length of the fruiting column during the study period in different papaya genotypes.

Year	Fruiting Height (cm)					Length of the Fruiting Zone (cm)				
	PS-1-1	PS-2-1	PS-3-1	PS-5-1	Red Lady	PS-1-1	PS-2-1	PS-3-1	PS-5-1	Red Lady
2014–15	70 (55–105) ± 10	85 (50–120) ± 17	71 (45–120) ± 17	89 (75–105) ± 10	85 (65–115) ± 12	40 (15–75) ± 18	54 (10–115) ± 28	44 (15–90) ± 17	35 (15–60) ± 14	36 (20-55) ± 9
2015–16	102 (90–120) ± 9	83 (55–135) ± 15	67 (50–85) ± 8	83 (70–100) ± 7	100 (90–115) ± 9	45 (30–65) ± 11	78 (25–120) ± 23	67 (45–85) ± 10	71 (45–100) ± 15	49 (30–65) ± 9
2016–17	86 (65–110) ± 12	112 (70–150) ± 19	73 (55–95) ± 9	91 (65–120) ± 13	86 (70–115) ± 12	27 (15–60) ± 11	32 (15–55) ± 12	30 (15–60) ± 11	52 (15–100) ± 21	31 (15–55) ± 10
2017–18	–	77 (50–110) ± 10	62 (50–75) ± 6	83 (65–110) ± 9	90 (65–125) ± 10	–	54 (25–75) ± 13	64 (35–85) ± 11	67 (20–90) ± 16	54 (25–80) ± 13
2018–19	–	73 (50–95) ± 13	60 (45–90) ± 15	81 (60–145) ± 29	75 (60–100) ± 11	–	69 (45–90) ± 18	50 (15–75) ± 16	72 (40–110) ± 23	51 (15–75) ± 15
Average	86	86	67	85	87	37	57	51	59	44

[Average Value (Range) ± Standard Deviation].

The fruit yield data revealed the maximum value (19 kg/plant) in PS-1-1 while minimum yield (16 kg/plant) in PS-5-1 and Red Lady considering average yield of all five production cycles. Fruit yield within all five seasons ranged from 9 kg/plant to 19 kg/plant in Red Lady. Whereas yield variation in Pune Selections were recorded 14 kg/plant to 23 kg/plant in PS-1-1; 13 kg/plant to 25 kg/plant in PS-2-1; 11 kg/plant to 28 kg/plant in PS-3-1; and 10 kg/plant to 23 kg/plant in PS-5-1. Analysis of average value of all production cycles showed maximum fruit yield in PS-3-1 (28 kg/plant) in 2017–2018 and minimum in PS-5-1 (10 kg/plant) in 2014–2015 (**Table 3**). Singh et al. [12] in a study on genetic variability and correlation for vegetative, reproductive and yield attributing traits in papaya, found maximum fruiting zone in PS-3 (129.8 cm) followed by a hybrid of PS-3 (128 cm), the dioecious parent of PS-3-1.

Table 3. Papaya of different genotype: Fruit yield during the study period in different papaya genotypes.

Year	Fruiting Yield (kg/plant)				
	PS-1-1	PS-2-1	PS-3-1	PS-5-1	Red Lady
2014–15	22.63 (8.00–36.05) ± 8.19	19.66 (5.95–43.45) ± 11.27	16.38 (5.05–38.35) ± 8.54	10.05 (6.10–17.00) ± 4.63	9.46 (5.40–14.40) ± 3.86
2015–16	20.83 (7.05–49.35) ± 7.80	15.65 (6.60–32.15) ± 6.43	15.66 (5.95–29.55) ± 5.44	16.95 (7.85–33.05) ± 5.90	17.46 (6.25–43.35) ± 7.30
2016–17	14.23 (08.05–21.75) ± 5.36	16.59 (11.40–24.00) ± 4.11	11.15 (10.00–12.00) ± 10.33	15.99 (09.70–19.80) ± 3.26	15.47 (12.00–19.45) ± 3.48
2017–18	–	24.73 (6.50–53.50) ± 9.94	28.46 (11.80–51.56) ± 10.31	22.75 (5.60–47.60) ± 10.14	19.13 (5.40–37.32) ± 8.34
2018–19	–	13.37 (5.70–29.95) ± 9.64	20.46 (11.20–35.35) ± 6.56	14.62 (10.00–19.10) ± 3.57	17.00 (6.25–30.35) ± 6.07
Average	19.23(16)	18.00(15)	18.42(17)	16.07(12)	15.70(13)

[Average value (Range) ± Standard Deviation].

Represented images of Pune Selections and Red Lady displaying horticultural traits (plant growth, fruiting, and fruits characters) are depicted in **Figure 1** and

Table 4. Average fruit weight of PS-1-1 and PS-2-1 was higher than Red Lady and those of PS-3-1 and PS-5-1 was lower than Red Lady. Thickness of fruit pulp of all gynodioecious Pune lines was more than that of Red Lady. TSS of all lines was closer to that of Red Lady (**Table 4**).

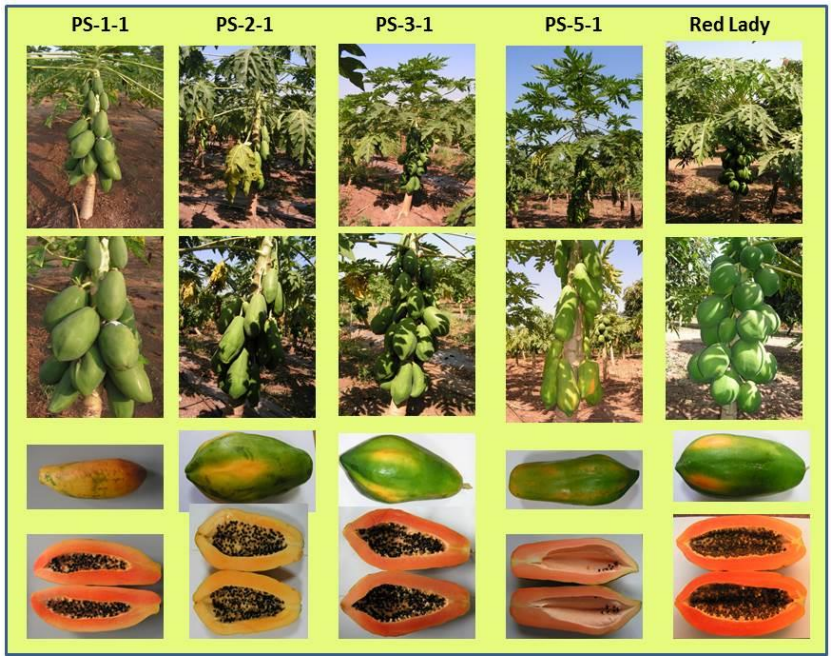

Figure 1. Horticultural characters of Pune Selections vis-à-vis Red Lady.

Table 4. Papaya of different genotype: Fruit characteristics of gynodioecious lines.

Year	Overall Average Value		
	Fruit Weight (g)	**Pulp Thickness (cm)**	**TSS(°Brix)**
PS-1-1	1478	3.40	7.95
PS-2-1	1438	3.57	8.73
PS-3-1	1196	3.34	9.00
PS-5-1	1211	2.88	8.61
Red Lady	1230	2.63	8.71

The ranges of standard deviation for various parameters in this study were acceptable as they were closer to their respective standard deviation ranges in Red Lady, a F_1 hybrid. (**Tables 1–3**).

Comparative PRSV disease intensity studies indicated lower disease incidence in 2017–18 in comparison to other production cycle years. Overall average data for the entire study period on PRSV–disease intensity showed maximum (30%) in PS-1-1 and minimum (16%) in PS-5-1. The highest average PRSV intensity of 48% was recorded in Red Lady. However, data of individual crop season showed the maximum PRSV intensity in PS-2-1 (48%) in 2015–16 and minimum in PS-2-1, PS-3-1 and PS-5-1 (0%) in 2017–18, while in Red Lady maximum PRSV intensity of 95% (2014–15) and the minimum of 6% (2017–18) was observed. In general, PS lines exhibited considerably lower PRSV intensity as compared to Red Lady (**Figure 2**). A similar PRSV reaction was reported by Chavan et al. [15] who screened eight

commercial papaya cultivars under Pune climate. They reported 13.2% PRSV incidence at full flowering stage in 'Madhubala' (parent material of Pune Selections) which was lowest when compared with Co.2 (39.8%), Pusa Nanha (44.8%) and Red Lady (86.0%).

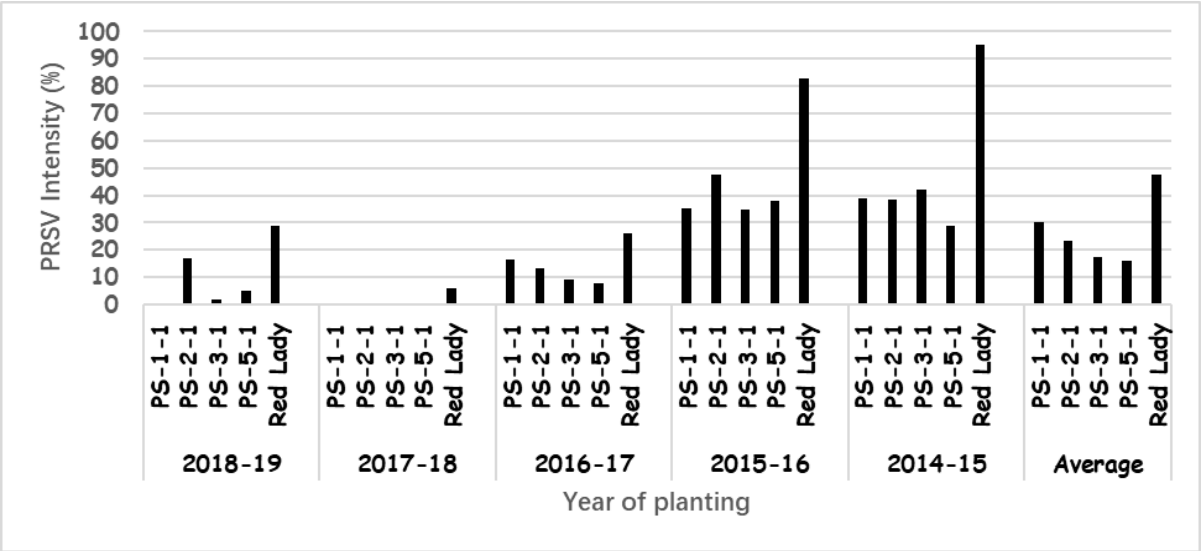

Figure 2. Papaya ringspot virus PRSV intensity (%) of gynodioecious Pune Selections lines vis-à-vis Red Lady.

4. Conclusion

Gynodioecious lines of papaya, namely, PS-1-1, PS-2-1, PS-3-1, and PS-5-1, developed by ICAR–Indian Agricultural Research Institute, Regional Station, Pune, were characterized against prevailing commercial gynodioecious cultivar, Red Lady. The plant height was the maximum in PS-2-1 and PS-5-1 (183 cm) and minimum in PS-3-1 (149 cm), while that of Red Lady was 158 cm. The stem girth of all lines was lower than that of Red Lady. The average value of fruiting height was maximum in PS-1-1 and PS-2-1 (86 cm) and minimum in PS-3-1 (67 cm) while that of Red Lady was 87 cm. The fruiting height of all lines was less than that of Red Lady (87 cm). Average length of fruiting column in PS-5-1 was the maximum (59 cm) whereas the minimum fruiting column (37 cm) was recorded in PS-1-1. Length of the fruiting column of all lines was more than that of Red Lady (37 cm), except in PS-1-1. The fruiting column in Red Lady (44 cm) was lower than that of all Pune Selections except for PS-1-1. The fruit yield data revealed the maximum value (19 kg/plant) in PS-1-1 while the minimum value (16 kg/plant) in PS-5-1 and Red Lady. The fruit yield of all lines, except PS-5-1, was more than that of Red Lady (16 kg/plant). The average fruit weight of PS-1-1 and PS-2-1 was higher than, and those of PS-3-1 and PS-5-1 was lower than, that of Red Lady. The thickness of fruit pulp of all gynodioecious Pune lines was more than that of Red Lady. TSS of all lines was closer to that of Red Lady. Intensity of PRSV infection in Red Lady (48%) was considerably more than all lines. These lines have the potential to be developed into PRSV tolerant gynodioecious papaya variety.

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SKS; resources, SKS and ST; data curation, SKS; writing—original draft preparation, SKS; writing—review and editing, SKS and ST; visualization, SKS; supervision, SKS; project administration, SKS; funding acquisition, SKS and ST. All authors have read and agreed to the published version of the manuscript.

Conflict of interest: The authors declare no conflict of interest.

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