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Enhancing the quality and yield of papaya (*Carica papaya* L.) cv. Red lady by application of plant elicitors

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Abstract
The experiment was carried out at Horticultural Research Station, Anantharajupeta, Kadapa district, Andhra Pradesh during 2015-16 and 2016-17 with the application of plant elicitors i.e different concentrations of salicylic acid (50 ppm, 100 ppm, 150 ppm), jasmonic acid (50 µM, 100 µM, 150 µM) once at 45 Days After planting and twice at 45 Days After Planting and 120 Days After Planting and control (no spray). The influence of plant elicitors was also found on fruit quality parameters at the time of harvest. T_9 (S.A @ 150 ppm at 45 DAT and 120 DAT) recorded significantly highest T.S.S (12.39 ^{o}Brix), total sugars (9.94%), reducing sugars (6.12%), non reducing sugars (3.97%) and sugar acid ratio (49.76) which were found at par with T_8 S.A @ 100 ppm at 45 DAT and 120 DAT (12.28 ^{o}Brix, 9.89%, 6.1%, 3.97% and 48.83) and T_7 (S.A @ 50 ppm at 45 DAT and 120 DAT) (12.21 ^{o}Brix, 9.77%, 6.01%, 3.81% and 46.51). The lowest values in this regard were recorded in T_{13} (control) (10.65 ^{o}Brix, 8.31%, 5.32%, 3.31% and 29.71). The lowest titrable acidity was recorded with T_9 (0.2) which was at par with T_8 (0.2) and T_7 (0.21). T_9 which was at par with T_8 and T_3 recorded significantly highest carotenoid content (1.88, 1.87 and 1.79) and the lowest carotenoid content was recorded in control (T_{13}) (1.35). Highest weight of fruits per plant (49.78 kg), yield per plot (552.42kg) and yield per hectare (116.06 tons) were found in T_9 which was at par with T_8 (47.17 kg, 546.59 kg and 114.83 tons ha^{-1}) respectively.

Keywords: Carotenoid content, fruit quality, papaya, plant elicitors

Introduction
Papaya (*Carica papaya* L.) belongs to the genus *Carica*, of the family Caricaceae. Papaya is being used since very long time for medicinal uses in day to day life. It has gained more importance owing to its high palatability, fruiting ability throughout the year, early fruiting and highest productivity. The important papaya growing states in the country are Tamil Nadu, Karnataka, Orissa, West Bengal, Assam, Gujarat, Andhra Pradesh, Bihar, Kerala, Maharashtra and Madhya Pradesh. Due to the favourable climatic conditions it performs better in south than in north, where low temperature and frost often limit its growth and productivity. In Andhra Pradesh it occupies an area of 13,560 ha with 12,88,580 MT of annual production. (Indiastat 2016-17) [8]. However, in Andhra Pradesh, major area is occupied by Taiwan variety Red lady. The area under this variety is continuously on rise because of its high yield potential, less water requirement and attractive prices in market. The crop is emerging as an alternative cash crop to banana, but cultivation of papaya is badly affected by number of production problems *viz*., viral attack, fungal diseases and mealy bug infestation. Hence, elicitors were used which have profound impact on not only improvement on growth but also on improving the quality of fruit and reduction of disease incidence. Jasmonic acid (JA) and Salicylic acid (SA) are two endogenous signalling molecules used in regulation of plant resistance to pathogens (Farousk and Osman, 2011) [6] and also possess crucial functions in mediating stress responses in plants. Further, it was also reported by Ahmed *et al.* (2015) [2] that three times of spray of salicylic acid at 200 ppm improved fruit TSS (19.1 and 19.1%), total sugars, reducing sugars and ascorbic acid content and also minimized the total acidity in ‘Sukkary’ mango. Strawberries treated with methyl jasmonate had higher soluble solids content (Abolfazl *et al*, 2013) [1].

Materials and Methods

The experiment was carried out at Horticultural Research Station, Anantharajupeta, Kadapa district, Andhra Pradesh, which is situated at an altitude of 162 meters (531 feet) above mean sea level and at 13.99º North latitude and 79.30º East longitude from November, 2015 to October, 2016 and November, 2016 to October, 2017. The experiment was laid out in a randomized block design with thirteen treatments and three replications. The treatments tested were application of salicylic acid @ 50 ppm (T_1), 100 ppm (T_2), 150 ppm (T_3) at 45 Days After Planting (DAP), jasmonic acid @ 50 µ M (T_4), 100 µ M (T_5), 150 µ M (T_6) at 45 DAP, salicylic acid @ 50 ppm (T_7), 100 ppm (T_8), 150 ppm (T_9) at 45 DAP and 120 DAP, jasmonic acid @ 50 µ M (T_{10}), 100 µ M (T_{11}), 150 µ M (T_{12}) at 45 DAP and 120 DAP and control (T_{13}). Fully ripe fruits were peeled and pulp was crushed for juice extraction. The juice was used for determining the soluble solids by using "Atago digital refractometer" with 0-32 range. The values were expressed as degree brix. The percentage of total sugars was estimated by A.O.A.C. (1980) [3] method. Carotenoids content in fruit pulp was estimated by following petroleum ether-acetone extraction method (Ranganna, 1986) [14]. Ascorbic acid content of papaya pulp samples was determined by 2, 6-dichlorophenol indophenol visual titration method described by Ranganna (1986) [14]. Fruits harvested from all the plants in all the plots according to treatment and replication were summed up for calculation of yield and expressed in kg per plot. This fruit yield thus obtained was extrapolated and expressed in tons per hectare.

Results and discussion

Fruit quality parameters

The influence of plant elicitors was also found on fruit quality parameters at the time of harvest. T_9 recorded significantly highest T.S.S (12.39 ºBrix), total sugars (9.94%), reducing sugars (6.12%), non reducing sugars (3.97%) and sugar acid ratio (49.76) which were found at par with T_8 (12.28 ºBrix, 9.89%, 6.1%, 3.97% and 48.83) and T_7 (12.21 ºBrix, 9.77%, 6.01%, 3.81% and 46.51) (Table 1). The lowest values in this regard were recorded in T_{13} (control) (10.65 ºBrix, 8.31%, 5.32%, 3.31% and 29.71).

In the present study the highest TSS content observed with salicylic acid treatment might be due to its dramatic effect on sugar metabolism. Salicylic acid improved the fruit quality by enhancing the accumulation of sugars through translocation of photo synthetic assimilates to fruits through break down of starch during ripening. (Raskin, 1992) [15] and also might have involved in the regulation of invertase, which plays an important role in hydrolysis of sucrose. (Leclere *et al.,* 2003) [11]. Sucrose content increases during ripening as a result to starch hydrolysis from increased amylase activity. (Tandon and Kalra, 1983) [19].

The lowest titrable acidity was recorded with T_9 (0.2) which was at par with T_8 (0.2) and T_7 (0.21) where in the highest value was recorded with T_{13} (0.28) (table 2). Low titrable acidity exhibited by fruits treated with salicylic acid might be due to delay in ripening as well as senescence processes resulting in the reduction of oxidation of acids (Islam *et al.*, 2013) [9]. T_9 which was at par with T_8 and T_3 recorded significantly highest carotenoid content (1.88, 1.87 and 1.79) and the lowest carotenoid content was recorded in control (T_{13}) (1.35) (Table 2). The promotive effect of salicylic acid on translocation of plant pigments and sugars (Raskin, 1992) [15] might have resulted in enhanced carotenoid content. Ascorbic acid content (mg 100 g^{-1}) was found to be significantly highest in T_8 (70.76) which was at par with T_9 (69.74) and the lowest was recorded with T_{13} (control) (64.24). The increase in ascorbic acid by salicylic acid treatment might be due to increase in lipid peroxidation (Jimenez *et al.*, 2002) [10]. Under such conditions the ascorbic acid content which is an antioxidant compound usually gets increased.

Yield parameters

Significant influence of different doses of plant elicitors on weight of fruits per plant in papaya upto 2nd harvest (Table 3). Whereas, in the third harvest, there was no significant difference observed among the treatments regarding weight of fruits per plant. The data during both the years of investigation and its pooled mean of total weight of the fruits showed that maximum total fruit yield per plant (49.85, 49.71 and 49.78 kg) was found by application of salicylic acid @ 150 ppm at 45 and 120 DAT (T_9) which was at par with T_8 (SA @ 100 ppm at 45 and 120 DAT) (47.80, 46.53 and 47.17 kg). Regarding yield per plot application of T_9 (SA @ 150 ppm at 45 and 120 DAT) during both the years of study and in its pooled mean bestowed the maximum fruit yield per plot (553.49, 551.35 and 552.42 kg) which remained statistically on a par with T_8 (SA @ 100 ppm at 45 and 120 DAT) (549.16, 544.02 and 546.59 kg) (Table 4). whereas, Yield per hectare also showed similar trend i.e During both the years of investigation and in its pooled mean application of T_9 (SA @ 150 ppm at 45 and 120 DAT) recorded maximum fruit yield per hectare (116.28, 115.83 and 116.06 tonnes respectively) which was at a par with application of T_8 (SA @ 100 ppm at 45 and 120 DAT) (115.37, 114.29 and 114.83 tonnes respectively) (Table 4).

The increased weight of the fruits per plant in present study by application of salicylic acid might be due to rapid cell division and cell enlargement and also due to hormone mediated direct transport, tolerance of plants to all stresses namely diseases, water and salt stresses and protects plant cells from oxidation by free radicals (Raskin, 1992) [15]. That might leads to enabling the shoot to meet the nutrient requirement of fruits throughout their development. Foliar application of salicylic acid number of chloroplast per cell, number of cells per leaf in pea, bean and cucumber (Possingham, 1980) [13] and in turn increased chlorophyll content of leaves (Singh *et al.*, 1993; Singh and Usha, 2003) [18, 17]. More accumulation of chlorophyll in leaves was reported by application of 100 ppm salicylic acid in tomato leaves (Senaratna *et al.*, 2000) [16]. In addition, application of salicylic acid reduces the production of ethylene farming enzyme (EFE) which will convert I-amino cyclopropane –I-carboxylic acid (ACC) to ethylene (Leslic and Romani, 1986) [12] leading to increased number of fruits by reduction of abscission of fruit and consequently increased the fruit yield per plant. Another reason for enhancement of yield by salicylic acid might be due to the tolerance of different biotic stresses by its antifungal, antibacterial properties and to different abiotic stresses like drought, temperature stress, salinity stress etc., (Gioushy, 2016) [7]. It was mainly because of enhanced activities of antioxidant enzymes including superoxide dismutase, catalase, ascorbate peroxidise and also by activating ascorbate – glutathione path way to protect the plants from oxidative burst. (Ding *et al.*, 2007; Cao *et al.*, 2009) [5, 14].

Table 1: Effect of salicylic acid and jasmonic acid on total soluble solids (°Brix), on total sugars (%), reducing sugars (%)and non-Reducing sugars (%) in papaya

Treatments	T.S.S (°Brix)			Total sugars (%)			Reducing sugars (%)			Non-Reducing sugars (%)		
	I Year 2015-16	II Year 2016-17	Pooled data	I Year 2015-16	II Year 2016-17	Pooled data	I Year 2015-16	II Year 2016-17	Pooled data	I Year 2015-16	II Year 2016-17	Pooled data
T_1: Salicylic acid @ 50 ppm at 45 DAT	11.65	11.42	11.54	9.26	8.95	9.11	5.65	5.46	5.55	3.61	3.50	3.55
T_2: Salicylic acid @ 100 ppm at 45 DAT	11.78	11.51	11.65	9.11	9.12	9.12	5.56	5.69	5.62	3.55	3.84	3.70
T_3: Salicylic acid @ 150 ppm at 45 DAT	11.81	11.68	11.75	9.33	9.40	9.37	5.53	5.85	5.69	3.80	3.55	3.67
T_4: Jasmonic acid @ 50 µM at 45 DAT	11.59	11.34	11.47	9.26	8.62	8.94	5.65	5.18	5.41	3.61	3.43	3.52
T_5: Jasmonic acid @ 100 µM at 45 DAT	11.53	11.28	11.41	9.14	9.18	9.16	5.39	5.65	5.52	3.75	3.53	3.64
T_6: Jasmonic acid @ 150 µM at 45 DAT	11.79	11.69	11.74	9.47	9.01	9.24	5.68	5.32	5.50	3.79	3.46	3.63
T_7: Salicylic acid @ 50 ppm at 45 DAT and 120 DAT	12.28	12.13	12.21	9.95	9.59	9.77	6.16	5.85	6.01	3.78	3.84	3.81
T_8: Salicylic acid @ 100 ppm at 45 DAT and 120 DAT	12.31	12.25	12.28	10.05	9.74	9.89	6.13	6.06	6.10	3.92	4.02	3.97
T_9: Salicylic acid @ 150 ppm at 45 DAT and 120 DAT	12.39	12.38	12.39	10.17	9.72	9.94	6.24	6.01	6.12	3.93	4.01	3.97
T_{10}: Jasmonic acid @ 50 µM at 45 DAT and 120 DAT	11.81	11.73	11.77	9.09	9.07	9.08	5.78	5.63	5.71	3.31	3.90	3.61
T_{11}: Jasmonic acid @ 100 µM at 45 DAT and 120 DAT	11.76	11.48	11.62	9.23	8.97	9.10	5.82	6.04	5.93	3.42	3.62	3.52
T_{12}: Jasmonic acid @ 150 µM at 45 DAT and 120 DAT	11.86	11.39	11.63	9.20	9.05	9.12	5.66	5.46	5.56	3.54	3.58	3.56
T_{13}: Control	10.74	10.56	10.65	8.28	8.34	8.31	5.22	5.42	5.32	3.06	3.57	3.31
S.Em. ±	0.09	0.11	0.07	0.09	0.10	0.08	0.14	0.17	0.11	0.08	0.10	0.06
C.D. at 5%	0.25	0.32	0.21	0.25	0.29	0.23	0.41	0.50	0.33	0.23	0.30	0.16

DAT: Days after transplanting

Table 2: Effect of salicylic acid and jasmonic acid on sugar acid ratio, titrable acidity (%), total carotenoids (mg 100 g^{-1}) content and ascorbic acid (mg 100 g^{-1}) content in papaya

Treatments	Sugar acid ratio			Titrable acidity (%)			Total carotenoids			Ascorbic acid		
	I Year 2015-16	II Year 2016-17	Pooled data	I Year 2015-16	II Year 2016-17	Pooled data	I Year 2015-16	II Year 2016-17	Pooled data	I Year 2015-16	II Year 2016-17	Pooled data
T_1: Salicylic acid @ 50 ppm at 45 DAT	36.55	34.06	35.31	0.25	0.26	0.26	1.57	1.56	1.57	65.85	65.44	65.65
T_2: Salicylic acid @ 100 ppm at 45 DAT	39.82	39.69	39.76	0.23	0.23	0.23	1.75	1.72	1.73	66.56	65.57	66.07
T_3: Salicylic acid @ 150 ppm at 45 DAT	42.47	36.20	39.34	0.22	0.26	0.24	1.79	1.79	1.79	68.62	68.32	68.47
T_4: Jasmonic acid @ 50 µM at 45 DAT	35.77	31.93	33.85	0.26	0.27	0.27	1.49	1.44	1.47	65.59	63.81	64.70
T_5: Jasmonic acid @ 100 µM at 45 DAT	38.29	36.81	37.55	0.24	0.25	0.25	1.73	1.72	1.73	66.39	67.08	66.74
T_6: Jasmonic acid @ 150 µM at 45 DAT	36.45	33.42	34.93	0.26	0.27	0.27	1.59	1.58	1.58	65.38	66.21	65.79
T_7: Salicylic acid @ 50 ppm at 45 DAT and 120 DAT	48.94	44.07	46.51	0.20	0.22	0.21	1.71	1.65	1.68	69.53	68.54	69.03
T_8: Salicylic acid @ 100 ppm at 45 DAT and 120 DAT	51.21	46.44	48.83	0.20	0.21	0.20	1.87	1.87	1.87	72.01	69.51	70.76
T_9: Salicylic acid @ 150 ppm at 45 DAT and 120 DAT	50.94	48.58	49.76	0.20	0.20	0.20	1.90	1.86	1.88	69.77	69.71	69.74
T_{10}: Jasmonic acid @ 50 µM at 45 DAT and 120 DAT	43.78	40.68	42.23	0.24	0.23	0.23	1.58	1.54	1.56	67.04	66.92	66.98
T_{11}: Jasmonic acid @ 100 µM at 45 DAT and 120 DAT	36.96	37.48	37.22	0.25	0.24	0.25	1.64	1.65	1.65	66.27	66.74	66.50
T_{12}: Jasmonic acid @ 150 µM at 45 DAT and 120 DAT	38.49	36.30	37.40	0.24	0.25	0.25	1.41	1.54	1.48	67.17	64.41	65.79
T_{13} : Control	29.60	29.82	29.71	0.28	0.28	0.28	1.35	1.34	1.35	64.53	63.95	64.24
S.Em. ±	1.70	1.50	1.27	0.008	0.008	0.006	0.04	0.04	0.03	0.85	0.77	0.48
C.D. at 5%	4.95	4.38	3.70	0.025	0.023	0.018	0.11	0.12	0.10	2.47	2.24	1.39

DAT: Days after transplanting

Table 3: Effect of salicylic acid and jasmonic acid on weight of fruits per plant (kg) in papaya

Treatments	1st harvest			2nd harvest			3rd harvest			Total weight of fruits per plant		
	I Year 2015-16	II Year 2016-17	Pooled data	I Year 2015-16	II Year 2016-17	Pooled data	I Year 2015-16	II Year 2016-17	Pooled data	I Year 2015-16	II Year 2016-17	Pooled data
T_1: Salicylic acid @ 50 ppm at 45 DAT	14.41	14.45	14.43	10.33	10.07	10.20	8.38	8.69	8.53	33.12	33.21	33.17
T_2: Salicylic acid @ 100 ppm at 45 DAT	15.64	14.85	15.24	11.01	10.56	10.78	8.74	8.12	8.43	35.39	33.53	34.46
T_3: Salicylic acid @ 150 ppm at 45 DAT	17.37	16.74	17.05	12.04	11.70	11.87	9.62	9.05	9.33	39.03	37.48	38.26
T_4: Jasmonic acid @ 50 µM at 45 DAT	12.83	13.39	13.11	10.14	10.39	10.26	8.71	9.52	9.12	31.69	33.30	32.49
T_5: Jasmonic acid @ 100 µM at 45 DAT	14.22	13.75	13.98	10.66	10.57	10.61	9.39	9.46	9.42	34.26	33.78	34.02
T_6: Jasmonic acid @ 150 µM at 45 DAT	14.13	13.96	14.04	11.05	10.65	10.85	9.03	9.43	9.23	34.21	34.04	34.12
T_7: Salicylic acid @ 50 ppm at 45 DAT and 120 DAT	20.03	18.52	19.27	13.01	12.53	12.77	8.26	9.43	8.84	41.29	40.48	40.89
T_8: Salicylic acid @ 100 ppm at 45 DAT and 120 DAT	22.66	22.47	22.57	15.42	14.08	14.75	9.72	9.98	9.85	47.80	46.53	47.17
T_9: Salicylic acid @ 150 ppm at 45 DAT and 120 DAT	23.34	23.23	23.28	16.71	16.38	16.54	9.80	10.10	9.95	49.85	49.71	49.78
T_{10}: Jasmonic acid @ 50 µM at 45 DAT and 120 DAT	14.58	14.39	14.49	10.61	11.11	10.86	9.36	9.43	9.40	34.56	34.93	34.74
T_{11}: Jasmonic acid @ 100 µM at 45 DAT and 120 DAT	15.05	14.51	14.78	11.36	11.35	11.35	9.42	9.19	9.31	35.83	35.05	35.44
T_{12}: Jasmonic acid @ 150 µM at 45 DAT and 120 DAT	15.15	14.82	14.98	11.84	11.71	11.78	8.90	9.19	9.04	35.89	35.72	35.80
T_{13}: Control	10.28	9.96	10.12	8.05	7.78	7.92	7.23	7.10	7.17	25.56	24.84	25.20
S.Em. ±	0.57	0.62	0.47	0.75	0.82	0.61	2.34	2.24	2.18	1.07	1.40	0.94
C.D. at 5%	1.65	1.83	1.37	2.18	2.38	1.77	NS	NS	NS	3.12	4.10	2.74

DAT: Days after transplanting

Table 4: Effect of pre-harvest spray of salicylic acid and jasmonic acid on on yield per plot (kg)(48.6 m^2), on yield per hectare (tons) in papaya

Treatments	Yield per plot (kg)(48.6 m^2)			Yield per hectare (tons)		
	I year 2015-16	II year 2016-17	Pooled data	I year 2015-16	II year 2016-17	Pooled data
T_1: Salicylic acid @ 50 ppm at 45 DAT	460.89	458.51	459.70	96.83	96.32	96.58
T_2: Salicylic acid @ 100 ppm at 45 DAT	496.99	478.46	487.72	104.41	100.52	102.46
T_3: Salicylic acid @ 150 ppm at 45 DAT	516.75	521.27	519.01	108.56	109.51	109.04
T_4: Jasmonic acid @ 50 µM at 45 DAT	435.83	455.72	445.78	91.56	95.74	93.65
T_5: Jasmonic acid @ 100 µM at 45 DAT	473.31	464.62	468.97	99.44	97.61	98.52
T_6: Jasmonic acid @ 150 µM at 45 DAT	474.95	470.58	472.77	99.78	98.86	99.32
T_7: Salicylic acid @ 50 ppm at 45 DAT and 120 DAT	529.69	527.98	528.84	111.28	110.92	111.10
T_8: Salicylic acid @ 100 ppm at 45 DAT and 120 DAT	549.16	544.02	546.59	115.37	114.29	114.83
T_9: Salicylic acid @ 150 ppm at 45 DAT and 120 DAT	553.49	551.35	552.42	116.28	115.83	116.06
T_{10}: Jasmonic acid @ 50 µM at 45 DAT and 120 DAT	482.91	476.54	479.72	101.45	100.11	100.78
T_{11}: Jasmonic acid @ 100 µM at 45 DAT and 120 DAT	492.38	482.81	487.59	103.44	101.43	102.44
T_{12}: Jasmonic acid @ 150 µM at 45 DAT and 120 DAT	499.02	496.31	497.67	104.84	104.27	104.55
T_{13}: Control	373.76	367.38	370.57	78.52	77.18	77.85
S.Em. ±	6.24	6.97	4.62	1.24	1.44	0.79
C.D. at 5%	18.21	20.36	13.49	3.63	4.21	2.31

DAT: Days after transplanting

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