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Growth, flowering and yield Responce of papaya (*Carica papaya* L.) cv. red lady to exogenous application of salicylic acid and Jasmonic acid

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Abstract
A field and laboratory study was carried out during November, 2015 to October, 2017 at Horticultural Research Station, Anantharajupeta, Kadapa district, Andhra Pradesh. The positive influence of application of salicylic acid @ 150 ppm twice at 45 and 120 DAT (T_9) was seen on significantly highest number of leaves (43.73) at 240 DAT which was at par with T_8 (42.73) and T_7 (41.07) and the lowest number of leaves was observed in T_{13} (control) (34.60). Further, the total chlorophyll content, chlorophyll a and chlorophyll b content were observed to be significantly high in T_9 (3.30, 2.04 and 1.25 mg g^{-1}) which was found to be at a par with T_8 and T_7. Number of days taken for initiation of flowering and days taken for 50% flowering were decreased significantly with the application of T_9 (114.33 DAT and 130.50 DAT respectively) which was found at par with T_8, T_2 and T_3. The corresponding values in control (T_{13}) were found to be much higher (127 and 147.80 respectively). Almost a similar trend was observed with respect to days for first fruit initiation and number of days taken to harvest, where in the values for T_9 were 146.66 DAT and 130.67 DAA respectively which were at par with T_8 (145.50 DAT and 131.66 DAA). The representing values for control (T_{13}) were 163.67 DAT and 146 DAA).Regarding yield parameters, highest yield per plot (kg) and yield per hectare (tons) were found to be highest in T_9 (552.42 kg and 116.06 tons ha^{-1}) which was at par with T_8 (546.59 kg and 114.83 tons ha^{-1}). The lowest values in this regard were recorded in control (T_{13}) (25.20 kg, 370.57 kg and 77.85 tons ha^{-1}).

Keywords: Chlorophyll content, flowering, papaya, salicylic acid

1. Introduction
Papaya (*Carica papaya* L.) belongs to the genus *Carica*, of the family Caricaceae. It is a tropical fruit central America and gained a lot of interest for its demand in international market. It has gained more importance owing to its high palatability, fruiting ability throughout the year, early fruiting and highest productivity. It contains papain, a commercially valuable photolytic enzyme that is produced in the milky latex of green, unripe fruits. This enzyme is used for tenderizing of meat. It is cultivated in the world in an area of 0.444 million ha with production of 12.67 million MT. In India it is grown in an area of 1,36,100 ha and annual production of 6.10 million MT with a productivity of 44.9 t ha^{-1}, whereas in Andhra Pradesh it occupies an area of 13,560 ha with 12,88,580 MT of annual production. (INDIASTAT, 2016-17). 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 is growing mainly in Chittoor, Ananthapuramu, Kadapa, Prakasam, and Vijayanagaram.

The area under papaya crop is growing continuously because of its high yield potential, attractive prices in market and less water requirement. The crop is badly affected by number of production problems *viz*., viral attack, fungal diseases and mealy bug infestation. Among these papaya ring spot virus (PRSV) has become a major threat to its production. An elicitor can be any naturally occurring plant compound or synthetic substance that initiates induced plant defence responses in the tissue comparable to natural defence induction against herbivores or pathogens. Jasmonic acid (JA) and Salicylic acid (SA) are two endogenous signalling molecules used in regulation of plant defence against pathogens (Farousk and Osman, 2011) [8]. Apart from that, both elicitors have impact on growth and development of the plants.

Salicylic acid (SA) (o-hydroxybenzoic acid), is a plant phenolic phytohormone distributed widely throughout the plant kingdom. SA is plays an important role in the regulation of growth and development of plants as it was reported that S.A influence ion uptake and transport, membrane permeability, photosynthetic rate, and transpiration (Khan *et al.,* 2003) [13]. Positive influence of Salicylic acid on plant height, carotenoids content, number of branches, chlorophyll content (Both chlorophyll a and b), leaves per plant, dry weight and shoot dry weight was also reported in tomato (Yildırım and Dursun, 2009) [28]. Salicylic acid was also found to induce flowering in many plants by acting as chelating agent due to its metal chelating activity on benzoic acid (Oota, 1975) [18]. Salicylic acid has an important regulatory role in flowering of thermogenic and odour-producing plants (Ozekar, 2005) [19].

The major function of JA is regulating plant responses to abiotic and biotic stresses and also plant growth and development processes include growth inhibition, flower development, senescence, and leaf abscission (Creelman and Mullet, 1997) [4]. Hence, the present investigation is proposed to study the effectiveness of foliar application of plant elicitors *viz.*, Salicylic acid and Jasmonic acid on growth, flowering, chlorophyll content and yield of papaya cv. Red lady.

Materials and Methods

The experiment entitled "Effect of plant elicitors on growth, yield, quality, PRSV incidence and post-harvest behaviour of Papaya (*Carica papaya*L.)cv. Red Lady." was carried out at Horticultural Research Station, Anantharajupeta, Kadapa district, Andhra Pradesh during the period from November, 2015 to October, 2016 and November, 2016 to October, 2017. The experiment was laid in randomised block design with thirteen treatments and three replications.

Details of the treatments

The experimental details with regards to application of plant elicitors (salicylic acid and jasmonic acid)

T_1 : Salicylic Acid @ 50 ppm at 45 DAT
T_2 : Salicylic Acid @ 100 ppm at 45 DAT
T_3 : Salicylic Acid @ 150 ppm at 45 DAT
T_4 : Jasmonic Acid @ 50 µ M at 45 DAT
T_5 : Jasmonic Acid @ 100 µ M at 45 DAT
T_6 : Jasmonic Acid @ 150 µ M at 45 DAT
T_7 : Salicylic Acid @ 50 ppm at 45 DAT and 120 DAT
T_8 : Salicylic Acid @ 100 ppm at 45 DAT and 120 DAT
T_9 : Salicylic Acid @ 150 ppm at45 DAT and 120 DAT
T_{10} : Jasmonic Acid @ 50 µ M at 45 DAT and 120 DAT
T_{11} : Jasmonic Acid @ 100 µ M at 45 DAT and 120 DAT
T_{12} : Jasmonic Acid @ 150 µ M at 45 DAT and 120 DAT
T_{13} : Control (No Spray).

*DAT:Days after transplanting

Results and Discussion

Number of leaves represent the photosynthetic infrastructure of the plant. The effect of different doses of plant elicitors on number of leaves per plant was presented in Table 1. Number of leaves ranged from 6.74 (in control at 150 DAT) to 43.73 (in T_9 at 240 DAT). Application of SA @ 150 ppm at 45 and 120 DAT (T_9) increased the number of leaves by 26.66, 29.56, 38.03, 26.38 per cent compared to control at 150,180,210 and 240 DAT respectively.

In the present study at 150 DAT, in pooled mean, highest number of leaves (33.87) was observed in T_9 (SA @ 150 ppm at 45 and 120 DAT), which was statistically at a par with T_8 (SA @ 100 ppm at 45 and 120 DAT) (33.00). Where as in pooled mean, at 180 DAT, highest number of leaves per plant (35.72) was observed in treatments T_9 which was statistically comparable with T_8 (34.50) and T_3 (33.93). At 210 DAT, during both the years of investigation and also in pooled mean, highest number of leaves per plant was noted with T_9 (SA @ 150 ppm at 45 and 120 DAT) (42.20, 44.46 and 43.33) which was statistically at a par with T_8 (39.60, 42.40 and 41.00), T_7 (38.53, 41.26 and 39.90) and T_3 (38.07, 40.00 and 39.03). At 240 DAT, in pooled mean, the treatment T_9 recorded highest number of leaves per plant (43.73) than the rest of the treatments except T_8 (42.73) and T_7 (41.07). Further, the total chlorophyll content, chlorophyll a and chlorophyll b content were observed to be significantly high in T_9 (3.30, 2.04 and 1.25 mg g^{-1}) which was found to be at a par with T_8 and T_7 (Table 2).However, the lowest chlorophyll content was recorded with T_{13} (Control) (2.06 mg g^{-1}).

Application of SA increased photosynthetic pigments content significantly and also increased chlorophyll content might be attributed to protection of plant cells from reactive Oxygen Species and other oxidation factors (Farouk, 2005) [7]. It was reported that S.A decreases ethylene production and subsequently increased chlorophyll (Leslie and Romani, 1986) and also activates the synthesis of carotenoids, which protect chlorophyll from oxidation. This increment of chlorophyll content might be also due to role of salicylic acid by enhancing the efficacy of photosynthetic apparatus with a more potential for resistance to decrease in photophosphorylation rate usually occurr after infection (Amaresh and Bhatt, 1998) [2].

Recent evidences also suggest that salicylic acid is enhances the activity of enzymes such as RuBisCO (Ribulose-1, 5-bisphosphate carboxylase/oxygenase) and carbonic anhydrase (Slaymaker *et al.,* 2002) [25]. Uzunova and Popova (2000) [26] further reported that salicylic acid affects leaf chloroplast structure. Similar report of increased chlorophyll content in leaves by application of salicylic acid were also reported by Senaratna *et al.*, (2000) [23] in tomato, Khan *et al.* (2003) [13] in soybean, Iqbal *et al.* (2006) [11] in wheat, Elshraiy and Hegazi (2007) [5] in pea, Ahmed *et al.* (2015) [1] in mango and Gioushy (2016) [9] in navel orange.

The results from this experiment also reported an early flowering with the application of SA @ 100 ppm and 150 ppm at 45 and 120 DAT (T_8 and T_9) in papaya cv. Red Lady. Number of days taken for initiation of flowering and days taken for 50% flowering were decreased significantly with the application of T_9(114.33 DAT and 130.50 DAT respectively) which was found at par with T_8, $T_2$and T_3. The corresponding values in control (T_{13}) were found to be much higher (127 and 147.80 respectively) (Table 3). Almost a similar trend was observed with respect to days for first fruit initiation and number of days taken to harvest, where in the values for T_9were 146.66 DAT and 130.67 DAA respectively which were at par with T_8 (145.50 DAT and 131.66 DAA). The representing values for control (T_{13}) were 163.67 DAT and 146 DAA.

Application of SA @100 ppm and 150 ppm at 45 DAT induced early flowering in papaya. Flowering was appeared before initiation of second dose of salicylic acid in these treatments. One hypothesis suggests that salicylic acid induces flowering by acting as a chelating agent because, the free o-hydroxyl group confers metal chelating activity on

benzoic acids (Oota, 1975) [18]. It confers more availability of nutrients which leads to induce flowering in Lemnaceae by chelating agents (Oota, 1972 and Seth *et al.*, 1978) [17, 24]. Flower stimulation was observed by Salicylic acid in various genera of Lemnaceae family, including long day, short day and photoperiod insensitive types (Khurana and Cleland, 1992) [14].

Watanabe *et al.* (1981) [27] also reported SA as endogenous growth regulator for flowering and florigenic effect. Salicylic acid minimized the days taken to flowering because of its role as a plant morphogenetic regulator. The reports on florigenic effects of exogenous application of salicylic acid was demonstrated in *Oncidium, Impatiens* and *Spirodela punctata* (Raskin, 1992) [21].

In papaya, advancement in respect of days to flowering, days to 50% flowering, days to first fruit formation, days to harvest might also be due to stimulation of alternate respiration by SA. According to Padmapriya and Chezhiyan (2002) [20] the favourable effects of SA on flowering performance of chrysanthemum might be due to synergism between IAA and phenolics they also mentioned that alternate respiration played an important role in flower induction.

Yield parameters were also influenced significantly by the application of salicylic acid @ 150 ppm at 45 and 120 DAT (T_9). yield per plot (kg) and yield per hectare (tons) were found to be highest in T_9 (552.42 kg and 116.06 tons ha^{-1}) which was at par with T_8 (546.59 kg and 114.83 tons ha^{-1}) (Table 4). The lowest values in this regard were recorded in control (T_{13}) (370.57 kg and 77.85 tons ha^{-1}).

The increase of yield parameters by application salicylic acid might be due to greater chlorophyll accumulation, carbonic anhydrase activity and rubisco activity. This in turn enhanced more translocation of photo assimilates to fruits that leads to the more photosynthetic rate. Increasing of yield by salicylic acid might also be due to inhibition of incidence of PRSV by induction of SAR in plants by induced PR protein synthesis or by increasing the enzyme activities of peroxidase, poly phenol oxidase apart from higher accumulation of phenols. Inhibition of ethylene biosynthesis by salicylic acid could also another reason for increased number of fruits and there by increased yield.

Enhancement of yield by salicylic acid might be due to enhancement of tolerance to different biotic stresses by pathogens by its antifungal, antibacterial properties and to different abiotic stresses like drought, temperature stress, salinity stress etc. and also by enhancement of antioxidant enzymes including superoxide dismutase, ascorbate peroxidise, catalase, and also by activating ascorbate – glutathione path way which will protect the plants from oxidative burst. Similar increase in yield by salicylic acid application was reported by Faissal *et al.* (2014) [6], Ngullie *et al.* (2014) [16] in mango, kassem *et al.* (2011) [12] in jujube, Saied (2011) [22] in william bananas, Gioushy (2016) [9] in Washington navel orange and Bindhyachal *et al.* (2016) in guava.

Table 1: Effect of salicylic acid and jasmonic acid on number of leaves per plant in papaya

Treatments	Number of leaves per plant											
	150 DAT			180 DAT			210 DAT			240 DAT		
	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	31.13	28.80	29.97	32.40	30.20	31.30	36.13	36.93	36.53	37.80	39.60	38.70
T_2 : Salicylic acid @ 100 ppm at 45 DAT	31.47	29.27	30.37	32.00	32.33	32.17	37.06	38.86	37.96	38.26	40.20	39.23
T_3 : Salicylic acid @ 150 ppm at 45 DAT	32.33	31.20	31.77	34.33	33.53	33.93	38.07	40.00	39.03	39.00	41.73	40.37
T_4 : Jasmonic acid @ 50 µM at 45 DAT	31.07	28.67	29.87	32.53	30.07	31.30	35.67	38.20	36.93	38.00	38.73	38.37
T_5 : Jasmonic acid @ 100 µM at 45 DAT	30.07	29.07	29.57	31.53	29.20	30.37	37.47	37.67	37.57	37.73	39.73	38.73
T_6 : Jasmonic acid @ 150 µM at 45 DAT	30.93	26.60	28.77	32.93	30.53	31.73	37.87	38.86	38.37	38.87	40.20	39.54
T_7 : Salicylic acid @ 50 ppm at 45 DAT and 120 DAT	31.80	31.80	31.80	33.13	31.87	32.50	38.53	41.26	39.90	41.33	40.80	41.07
T_8 : Salicylic acid @ 100 ppm at 45 DAT and 120 DAT	32.40	33.60	33.00	34.00	35.00	34.50	39.60	42.40	41.00	41.73	43.73	42.73
T_9 : Salicylic acid @ 150 ppm at 45 DAT and 120 DAT	34.33	33.40	33.87	36.47	34.97	35.72	42.20	44.46	43.33	42.87	44.60	43.73
T_{10} : Jasmonic acid @ 50 µM at 45 DAT and 120 DAT	31.20	31.20	31.20	34.80	32.53	33.67	37.93	38.20	38.07	40.70	39.47	40.08
T_{11} : Jasmonic acid @ 100 µM at 45 DAT and 120 DAT	31.67	28.73	30.20	33.53	31.20	32.37	37.00	37.00	37.00	38.47	38.73	38.60
T_{12} : Jasmonic acid @ 150 µM at 45 DAT and 120 DAT	30.20	28.80	29.50	31.53	30.27	30.90	37.33	36.87	37.10	38.53	38.33	38.43
T_{13} : Control	28.00	25.47	26.74	28.73	26.40	27.57	31.98	30.80	31.39	33.60	35.60	34.60
S.Em±	0.80	1.26	0.67	0.92	0.80	0.63	1.34	1.80	1.54	1.30	1.34	0.94
C.D. at 5%	2.34	3.69	1.96	2.68	2.33	1.83	3.92	5.25	4.52	3.78	3.92	2.75

Table 2: Effect of salicylic acid and jasmonic acid on total chlorophyll (mg g^{-1}), chlorophyll 'a'(mg g^{-1})and chlorophyll 'b'(mg g^{-1}) in papaya

Treatments	Total chlorophyll			Chlorophyll 'a'			Chlorophyll 'b'		
	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	2.76	2.84	2.80	1.68	1.74	1.71	1.08	1.10	1.09
T_2: Salicylic acid @ 100 ppm at 45 DAT	2.73	2.65	2.69	1.77	1.65	1.71	0.96	0.99	0.97
T_3: Salicylic acid @ 150 ppm at 45 DAT	2.86	2.81	2.83	1.78	1.76	1.77	1.07	1.04	1.06
T_4: Jasmonic acid @ 50 µM at 45 DAT	2.83	2.46	2.64	1.76	1.55	1.66	1.07	0.91	0.99
T_5: Jasmonic acid @ 100 µM at 45 DAT	2.55	2.34	2.44	1.62	1.43	1.53	0.93	0.91	0.92
T_6: Jasmonic acid @ 150 µM at 45 DAT	2.53	2.18	2.35	1.55	1.36	1.45	0.98	0.82	0.90
T_7: Salicylic acid @ 50 ppm at 45 DAT and 120 DAT	3.17	2.97	3.07	1.98	1.81	1.90	1.19	1.16	1.17
T_8: Salicylic acid @ 100 ppm at 45 DAT and 120 DAT	3.19	3.22	3.20	2.00	1.96	1.98	1.19	1.25	1.22
T_9: Salicylic acid @ 150 ppm at 45 DAT and 120 DAT	3.34	3.26	3.30	2.11	1.98	2.04	1.23	1.28	1.25
T_{10}: Jasmonic acid @ 50 µM at 45 DAT and 120 DAT	2.86	2.43	2.65	1.79	1.49	1.64	1.07	0.94	1.01
T_{11}: Jasmonic acid @ 100 µM at 45 DAT and 120 DAT	2.88	2.36	2.62	1.80	1.47	1.64	1.08	0.89	0.99
T_{12}: Jasmonic acid @ 150 µM at 45 DAT and 120 DAT	2.77	2.36	2.57	1.69	1.44	1.57	1.08	0.91	1.00
T_{13}: Control	2.23	1.89	2.06	1.36	1.17	1.26	0.87	0.72	0.80
S.Em. ±	0.12	0.12	0.09	0.06	0.03	0.03	0.04	0.04	0.03
C.D. at 5%	0.34	0.35	0.26	0.18	0.08	0.09	0.13	0.13	0.09

Table 3: Effect of salicylic acid and jasmonic acid on flowering parameters in papaya

Treatments	Days taken for initiation of flowering(DAT)			Day taken for 50 percent flowering(DAT)			Days taken for first fruit formation(DAT)			Days to harvest(DAA)		
	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	117.33	117.33	117.33	133.67	139.00	136.33	148.33	152.00	150.17	138.00	137.00	137.50
T_2: Salicylic acid @ 100 ppm at 45 DAT	111.00	114.33	112.67	132.00	134.33	133.17	148.33	147.66	148.00	137.00	137.33	137.16
T_3: Salicylic acid @ 150 ppm at 45 DAT	114.67	116.67	115.67	134.33	136.00	135.17	149.00	152.33	150.67	136.33	138.33	137.33
T_4: Jasmonic acid @ 50 µM at 45 DAT	116.33	118.33	117.33	134.67	137.66	136.16	151.33	154.00	152.67	137.67	139.00	138.33
T_5: Jasmonic acid @ 100 µM at 45 DAT	123.67	124.00	123.83	141.67	144.00	142.83	156.00	158.50	157.25	141.00	143.33	142.17
T_6: Jasmonic acid @ 150 µM at 45 DAT	119.33	121.67	120.50	136.33	141.66	139.00	151.33	157.33	154.33	136.33	139.33	137.83
T_7: Salicylic acid @ 50 ppm at 45 DAT and 120 DAT	116.67	118.67	117.67	133.67	134.33	134.00	147.67	151.33	149.50	133.67	135.33	134.50
T_8: Salicylic acid @ 100 ppm at 45 DAT and 120 DAT	112.00	113.33	112.67	127.00	130.33	128.67	145.67	145.33	145.50	128.67	132.67	130.67
T_9: Salicylic acid @ 150 ppm at 45 DAT and 120 DAT	113.33	115.33	114.33	130.67	130.33	130.50	143.67	149.66	146.66	132.67	130.66	131.66
T_{10}: Jasmonic acid @ 50 µM at 45 DAT and 120 DAT	118.67	119.67	119.17	133.67	136.66	135.16	146.00	153.33	149.67	135.67	138.00	136.83
T_{11}: Jasmonic acid @ 100 µM at 45 DAT and 120 DAT	122.33	124.67	123.50	140.33	143.33	141.83	154.33	159.66	157.00	139.33	143.33	141.33
T_{12}: Jasmonic acid @ 150 µM at 45 DAT and 120 DAT	118.67	121.33	120.00	137.33	141.66	139.50	150.67	157.33	154.00	136.33	141.66	139.00
T_{13}: Control	125.33	128.67	127.00	144.67	150.33	147.50	162.00	165.33	163.67	143.00	150.33	146.67
S.Em. ±	1.29	1.32	1.04	2.17	1.97	1.59	1.30	2.19	1.22	1.95	1.45	1.07
C.D. at 5%	3.78	3.85	3.02	6.34	5.76	4.63	3.79	6.39	3.57	5.69	4.24	3.13

DAT: Days after transplanting; DAA: Days after anthesis

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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