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# Effect of plant growth regulators on fruit quality of papaya

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**Abstract**
Papaya (*Carica papaya* L.) is a very important tropical fruit crop, widely grown across the world with many nutritional and medicinal benefits. During the ripening process, major hormonal changes occur, which gives a better scope for quality improvement by applying plant growth regulators exogenously. In the present study, different plant growth regulators, *viz.* ethrel (100, 120 ppm), ABA ($10^{-6}$ M, $10^{-4}$ M) and MeJA ($10^{-5}$ M, $10^{-3}$ M) were applied at 140 days old fruit (DOF) to know their effect on fruit physico-chemical parameters at ripening. Among all the treatments, application of 120 ppm ethrel improved the peel ($L^*$ 61.00, $a^*$ 12.50 and $b^*$ 38.23) and pulp ($L^*$ 47.70, $a^*$ 25.96. and $b^*$ 33.80) colour, TSS (11.36 $^0$B), reducing sugars (3.14%), total sugars (7.67%), flavonoids (21.18 mg/100 g), CUPRAC activity (4.77 µmol/g) and lycopene content (3.78 mg/100 g) of fruits, while, total phenols (24.01 mg GAE/100 g), ascorbic acid (81.42 mg/100 g), total carotenoids (4.22 mg/100 g), and β-carotene content (3.74 mg/100 g) were enhanced after the application of the $10^{-5}$ MeJA. It was also observed that a higher concentration of ABA ($10^{-4}$ M) did not prove better than ethrel and MeJA, although it was found to be slightly superior over the control for most of the parameters.

**Keywords:** *Carica papaya* L., ethrel, ABA, MeJA, ripening and fruit quality

## 1. Introduction

India is the largest producer of papaya in the world and shares 44.4% of the total globe's production, with a productivity of 43.3 t/ha (ICAR-Databook, 2019) [8]. A nutritious diet is essential for good health, especially during the Covid-19 situation, where our immune system has been affected. Fruit crops like papaya, which is high in vitamin A and C, plays an important role to fight against such illnesses (Aman and Masood, 2020) [1]. Papaya is the second richest source of vitamin-A among all major fruit crops, next to mango, ranging from 18 to 74 g/100 g RAE (Retinol activity equivalents).

The nutritional quality of the papaya fruit depends on the variety, growing conditions, and ripeness upon consumption. During the ripening process, major hormonal changes occur, which give a better scope for quality improvement by applying plant growth regulators (PGRs) exogenously. Most often, the fruit ripening period in northern India coincides with severe cold stress followed by warm sunny days as well as unseasonal rains, which affect the fruit's palatable quality. Previously, much research has been done on exogenous treatment of different PGRs such as auxins, gibberellins and cytokinins for the improvement of papaya fruit quality. But still a lot of research is needed to improve the fruit quality with respect to various aspects. Papaya is a climacteric fruit and synthesis of sugars and different acidic compounds are activated only a few days before full ripening. Therefore, it is very important to understand the role of different hormones at this particular stage.

Ethylene is a gaseous phytohormone with several roles in plant growth and governs firmness and colour changes in climacteric fruits during ripening, including chlorophyll degradation and rise in carotenoids, sugars, and biosynthesis of volatile organic compounds. The effect of ABA on papaya fruit ripening and its relationship to ethylene revealed that its production increased with fruit ripening, while fruit firmness declined sharply with advancement of the ripening process. Exogenous ABA application accelerated the fruit softening by increasing ethylene production, fruit firmness reduction, soluble solids accumulation, and fruit pigment formation. Jasmonates (JAs), which include jasmonic acid and its methyl ester, are lipid-derived chemicals that have signaling roles in plant growth and development as well as stress responses. It is well known that MeJA significantly affected the physical, chemical, and pigment content of fruits as well as their size, colour and firmness (Ozturk *et al*., 2015) [14].

However, there is meagre report on the fruit quality improvement in papaya with the use of ABA and MeJA. Therefore, the present investigation has been undertaken with the objective to find out the response of ethylene, abscisic acid and methyl jasmonate on fruit physico-chemical parameters at ripening.

## 2. Material and Methods

### 2.1 Experimental site

The present experiment was conducted in the insect proof net house of the Division of Fruits and Horticultural Technology, ICAR- ARI, New Delhi during March, 2021; which is located at 77°12'E longitude, 28°40'N latitude, and an altitude of 228.6 m above mean sea level.

### 2.2 Experimental materials

Three bearing papaya plants of var. Pusa Nanha was selected under each treatment. All the standard cultural practices were followed for raising a healthy papaya crop.

### 2.3 Solution preparation

ll the spray solutions were prepared on the same day of application. For the preparation of 100 and 120 µl $L^{-1}$ ethephon solution, 100 and 120 µl a.i. ethrel were taken out with the help of a micropipette and the volume was made upto one liter double-distilled water. For the preparation of $10^{-4}$ and $10^{-6}$ M ABA solutions, 26.4 and 0.264 mg ABA, respectively, in powdered extra pure form was taken to an Erlenmeyer flask and dissolved in 10 ml of ethyl alcohol and the final volume was made up by adding distilled water. For the preparation of $10^{-3}$ and $10^{-5}$ M MeJA solutions, 224 and 2.24 µl MeJA in pure liquid form were respectively measured accurately with the help of a micropipette and dissolved in 10 ml of ethyl alcohol and the final volume was made up of one litre with double- distilled water.

### 2.4 Application of PGRs

Fruits of the papaya var. Pusa Nanha of 140-day-old after pollination were chosen and dipped in plant growth regulator soultions. The fruits were dipped in well-sealed polyethylene plastic bags (30 × 30 $cm^2$) containing 100 ml of a prepared solution of ethrel, abscisic acid, methyle jasmonate as growth regulators, and double-distilled water as a control. Fruits were retained on tree in plastic bags for 3 min. after the treatment. All the treated fruits were harvested during morning hour when the yellow streaks pigmentation appears on the upper surface of the fruits.

### 2.5 Statistical design

All the experiments were conducted in the randomized block design with three replications and analyzed using OP STAT (Sheoran *et al*., 1998) [17].

## 3. Results and Discussion

### 3.1 Days to fruit harvesting

In the present experiment minimum days to first fruits harvest was observed with MeJA $10^{-3}$ M (147.67 days) treated fruit, followed by ethrel 120 ppm (148.33 days) and ABA $10^{-4}$ M (151.67 days), while the control (154.67 days) treated fruits were picked at the last. Earlier, Fan *et al.* (1998) [5] also observed that exogenous application of jasmonates at lower concentrations (1 or 10 M) promoted ethylene production and led to early ripening in apple and tomato.

### 3.2 Physical parameters

Exogenous application of different concentration of ehtrel, ABA and MeJA did not improve the physical parameters like fruit length, diameter, weight, cavity index, pulp thickness and number of seeds of papaya. Since spraying was done on matured fruits (140-day- old) where the fruits had already achieved their full morphological growth, might be the reason for no significant changes observed on these parameters. The maximum fruit firmness (20.53 N) was found in ABA $10^{-6}$ M, while minimum (11.67 N) was observed in ethrel 120 ppm. Loss in firmness was also observed by Lavanya *et al.* (2020) [10] in papaya cv. Red Lady with ethylene gas. Apart from ethrel treated fruits significant loss in firmness was also noticed in the case of MeJA treated fruits. Sunrise papaya (Gonzalez *et al.*, 2003) [6] showed loss in firmness with increase in the concentrations of MeJA (Table 1).

### 3.3 Colour intensity of peel

Outer colour of the fruit is one of the most important factors influencing consumer buying decisions. Fruits usually become yellow as a result of the breakdown of photosynthetic pigments such as chlorophyll in response to increased ripening. Fruits treated with ethrel 120 ppm gave better colour intensity ($L$* 63.96, $a$* 18.06, $b^*$ 38.23) It may be due the increased synthesis of caricaxanthin. Similar findings were also observed by Lavanya *et al.* (2020) [10] with papaya cv. Red Lady and climacteric fruits like pineapple, mango and tomato (Wang *et al*., 2018) [19].

### 3.4 Colour intensity of pulp

As regards fruit pulp colour, fruits treated with ethrel 120 ppm ($L^*$ 47.70, $a^*$ 25.96 and $b^*$ 33.80) gave better colour intensity as compared to ABA $10^{-6}$ M ($L^*$ 40.3, $a^*$ 27.06 and $b^*$ 30.16) and MeJA $10^{-5}$ M ($L^*$ 36.63, $a^*$ 27.66 and $b$* 29.16). It may be due to the higher carotenoid levels in ethrel-treated fruits might be attributed to increased activity of the carotenoid-hydroxylase enzyme, which is responsible for carotene biosynthesis. Similar finding with ethrel was also reported by Bal *et al*. (1990) [2] in papaya var. CO1 and CO2 (Table1). On the basis of maturity, Greensill and Newman (1999) [7] classified papaya seeds into four categories and found white seeds from immature fruit, grey to black colour seeds from transition stage fruit and both mature green and colour break stage fruit produce black to dark black seeds.

### 3.5 Seed colour

Till date there is no work reported on the effect of exogenous application with different plant growth regulators on papaya seed colour. In the present study, control fruits displayed the best dark seed colour (79.00%), followed by ethrel 100 ppm (64.00%) treated fruits. ABA $10^{-4}$ M had a negative effect on the seed colour (Fig. 2) and produced the least number of black seeds and produced maximum tan colour seeds (43%). It is also well known that during the seed maturation phase, ABA inhibits embryo growth and seed development.

### 3.6 Total soluble solids

Total soluble solids are one of the most important quality parameters of papaya. Papaya grown in polyhouses, has higher TSS ($11.2^0$Brix) than the open conditions (Prakash *et al*., 2015) [15]. There was a significant effect of plant growth regulators on the TSS of fruits. The maximum TSS (11.36 $^0$Brix) was found in the fruits treated with ethrel 120 ppm and the minimum (9.26 $^0$Brix) was found in the fruits treated with ABA $10^{-4}$ M. These results are in close conformity with the findings of Wang *et al*. (2018) [19] in blueberry (*Vaccinium virgatum*). Similar findings were also reported by Dubey *et al*. (2020) [3] in papaya.

### 3.7 Total phenols
Total phenolic Total phenolic compounds are essential plant compounds with antioxidant activity owing to their redox properties. In addition to the defensive mechanism, there is a positive relationship between phenolic content and antioxidant activity in the fruits. Fruits treated with MeJA $10^{-3}$ M had the highest total phenol content (27.18 mg GAE/100 g), whereas controls had the lowest (16.49 mg GAE/100 g). The present findings are in the close conformity with the Karaman *et al.* (2013) [9] in plum. Ozturk *et al.* (2015) [14] also found similar results in apples with MeJA at doses of 1120, 2240, and 4480 mg/L.

### 3.8 Acidity
There was no significant effect of plant growth regulators on acid content of the fruits. However, the fruits treated with ethrel 120 ppm had the minimum acidity (0.10%) and the maximum acidity was found with treatments of ABA $10^{-6}$ M, and MeJA $10^{-5}$ M. (0.18%). Similar result was reported by Dubey *et al.* (2020) [3] in papaya with pre-harvest application of 150 ppm ethrel.

### 3.9 Reducing sugars
The maximum reducing sugars (3.14%) and total sugars (7.67%) were found in ethrel 120 ppm and minimum reducing sugars (2.61%) and total sugars (5.50%) were observed in ABA $10^{-6}$ M treated fruits. These findings suggested that ethylene has an influence on soluble sugar build up in the ripened papaya. Fabi *et al*. (2007) [4] reported that 1-MCP-treated papayas had a distinct pattern of sucrose production during ripening as compared to untreated papayas. Lavanya *et al.* (2020) [10] conducted an experiment on papaya Cv. Red Lady and observed that exposing papaya fruits to ethylene gas in a ripening chamber triggered the ripening process and increased the reducing sugars content (Table 2).

### 3.10 Antioxidants
Antioxidants are chemical substances that can bind to free oxygen radicals and protect them from harming healthy cells. Maximum flavonoids content (21.18 mg/100 g) was observed in the fruits treated with ethrel 120 ppm followed by MeJA $10^{-3}$ M (21.03 mg/100 g) and the minimum was found in ABA $10^{-6}$ M (17.18 mg/100 g). Whereas, CUPRAC activity was found maximum in fruits treated with ethrel 120 ppm (4.77 mol/g) followed by MeJA $10^{-3}$ M (4.47 mol/g) and minimum in control (4.46 mol/g). Singh and Dwivedi (2008) [18] studied the effect of ethrel and 1-methylcyclopropene (1-MCP) on antioxidant activities of mango fruit and concluded that the activity of ascorbate peroxidase (APX), an antioxidant enzyme, was drastically increased in the ethrel treated fruits.

### 3.11 Ascorbic acid content
Flavonoids, antioxidant activity and phenolic compounds increased in the plum fruits treated with MeJA two weeks before harvest (Karaman *et al*., 2013) [9]. Maximum ascorbic acid content (81.42 mg/100 g) was observed in the fruits treated with MeJA $10^{-5}$ M and the minimum (69.27 mg/100 g) was found in the control. Similar result was also observed by Muengkaew *et al.* (2016) [13] in *Mangifera indica* and found that pre-harvest application.

### 3.12 Total carotenoid and β-carotene content
MeJA had significantly higher phenylalanine-carotene and ascorbic acid content. The maximum β-carotene (3.74 mg/100 g) and total carotenoids content (4.22 mg/100 g) was found in the fruits treated with MeJA $10^{-5}$ M and minimum β-carotene (2.54 mg/100 g) and total carotenoids (3.67 mg/100 g) was found in fruits treated with ABA-$10^{-4}$ M. A similar response of MeJA with reference to the carotene content of tomato fruits was also observed by Saniewski *et al.* 1987 [16] and reported that exogenous application of jasmonates increased the ethylene production, which promotes climacteric fruit ripening by accelerating the breakdown of chlorophyll and the development of β-carotene. Mattheis *et al.* 2002 [12] investigated the role of MeJA against ethylene in the immature Fuji variety of apple and found that exogenous application of MeJA stimulates ß-carotene synthesis and was further stimulated by MJ plus ethylene, but not by ethylene alone.

### 3.13 Lycopene content
As regards lycopene, the maximum content (3.78 mg/100 g) was observed in the fruits treated with ethrel 120 ppm and the minimum (3.08 mg/100 g) was found in the fruits treated with MeJA $10^{-3}$ M. A similar finding was reported by Fan *et al.* 1998 [5] in apple and tomato. They reported that exogenous application of jasmonates at low concentrations (1 or 10 µM) stimulated ethylene biosynthesis and colour change in pre-climacteric fruit discs in a concentration-dependent manner, but prevented lycopene synthesis. These results are in close conformity with the findings of Liu *et al*. 2012 [11] in tomatoes (Table 2).

**Table 1.** Effect of ethylene, ABA and MeJA on physical attributes in papaya var. Pusa Nanha.

| Treatment | Days to fruit harvesting | Fruit length (cm) | Fruit diameter (cm) | Fruit weight (g) | Fruit firmness (N) | Pulp thickness (cm) | Cavity index (%) | No. of seeds | Colour intensity of peel | | | Colour intensity of pulp | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | $L^*$ | $a^*$ | $b^*$ | $L^*$ | $a^*$ | $b^*$ |
| Control | 154.67 | 16.03 | 10.94 | 1,007.00 | 19.33 | 2.98 | 25.96 | 367.66 | 49.03 | 10.63 | 37.63 | 43.28 | 29.40 | 32.46 |
| Ethrel-100 ppm | 150.00 | 16.39 | 12.31 | 1,011.67 | 12.33 | 2.99 | 26.56 | 331.66 | 60.86 | 15.90 | 47.23 | 46.73 | 33.03 | 33.30 |
| Ethrel- 120 ppm | 148.33 | 16.87 | 12.37 | 1,016.00 | 11.67 | 3.08 | 27.36 | 424.33 | 63.96 | 18.06 | 38.23 | 47.70 | 25.96 | 33.80 |
| ABA- $10^{-6}$ M | 153.67 | 16.37 | 12.05 | 1,019.00 | 20.53 | 2.96 | 26.60 | 404.66 | 58.50 | 18.03 | 48.60 | 40.30 | 27.06 | 30.16 |
| ABA-$10^{-4}$ M | 151.67 | 16.55 | 12.74 | 1,027.67 | 17.6 | 2.94 | 25.96 | 425.66 | 56.76 | 13.46 | 43.66 | 39.00 | 28.70 | 29.08 |
| MeJA-$10^{-5}$ M | 149.33 | 16.17 | 11.92 | 1,016.00 | 12.56 | 2.83 | 26.46 | 420.66 | 59.96 | 14.33 | 38.10 | 36.63 | 27.66 | 29.16 |
| MeJA-$10^{-3}$ M | 147.67 | 16.78 | 13.21 | 1,027.33 | 13.63 | 3.07 | 25.86 | 400.33 | 62.26 | 10.86 | 38.93 | 37.83 | 31.50 | 32.40 |
| Mean | 150.76 | 16.54 | 12.32 | 1017.80 | 15.37 | 2.97 | 26.34 | 407.52 | 58.76 | 14.47 | 31.51 | 41.64 | 29.04 | 31.40 |
| SE (m) | 1.25 | 0.24 | 0.20 | 4.49 | 0.68 | 0.07 | 0.32 | 12.78 | 0.85 | 0.35 | 0.53 | 0.47 | 0.42 | 0.59 |
| LSD ($p \leq 0.05$) | 3.92 | NS | NS | NS | 2.21 | NS | NS | NS | 2.61 | 1.08 | 2.54 | 1.46 | 1.38 | 2.56 |
| CV | 1.44 | 2.55 | 2.82 | 0.75 | 7.69 | 4.10 | 2.184 | 15.34 | 2.50 | 4.22 | 3.46 | 1.97 | 2.67 | 3.26 |

**Table 2:** Effect of ethylene, ABA and MeJA on biochemical attributes in papaya var. Pusa Nanha.

| Treatment | TSS (⁰Brix) | Total phenols (mg GAE/100 g) | Acidity (%) | Total sugars (%) | Reducing sugars (%) | Total flavonoids (mg/100 g) | CUPRAC activity (µmol/ g) | Ascorbic acid (mg/100 g pulp) | Total carotenoid (mg/100 g) | β-carotene (mg/100 g) | Lycopene (mg/100 g) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Control | 9.43 | 16.49 | 0.18 | 6.06 | 3.00 | 17.98 | 4.46 | 69.27 | 3.77 | 2.68 | 3.27 |
| Ethrel-100 ppm | 10.73 | 21.72 | 0.13 | 6.97 | 2.74 | 20.61 | 4.75 | 80.03 | 4.07 | 3.12 | 3.44 |
| Ethrel-120 ppm | 11.36 | 23.31 | 0.10 | 7.67 | 3.14 | 21.18 | 4.77 | 75.73 | 4.14 | 3.13 | 3.78 |
| ABA- $10^{-6}$ M | 9.73 | 16.54 | 0.18 | 5.50 | 2.61 | 17.18 | 4.63 | 80.27 | 3.70 | 2.67 | 2.87 |
| ABA- $10^{-4}$ M | 9.26 | 19.13 | 0.16 | 5.56 | 2.64 | 18.05 | 4.57 | 77.71 | 3.67 | 2.54 | 2.75 |
| MeJA- $10^{-5}$ M | 10.63 | 27.18 | 0.13 | 7.28 | 2.67 | 20.18 | 4.70 | 81.42 | 4.22 | 3.74 | 3.18 |
| MeJA- $10^{-3}$ M | 10.20 | 24.01 | 0.18 | 7.22 | 3.12 | 21.03 | 4.74 | 74.52 | 3.65 | 2.64 | 3.08 |
| Mean | 10.20 | 21.12 | 0.15 | 6.56 | 2.85 | 19.45 | 4.65 | 76.99 | 3.89 | 2.93 | 3.18 |
| SE(m) | 0.11 | 0.54 | 0.03 | 0.13 | 0.03 | 0.23 | 0.03 | 0.59 | 0.03 | 0.08 | 0.05 |
| LSD ($p \leq 0.05$) | 0.34 | 1.94 | NS | 0.41 | 0.11 | 0.67 | 0.08 | 1.85 | .10 | 0.24 | 0.15 |
| CV | 1.92 | 4.71 | 29.21 | 3.23 | 2.23 | 1.93 | 1.07 | 0.93 | 1.54 | 4.62 | 2.78 |

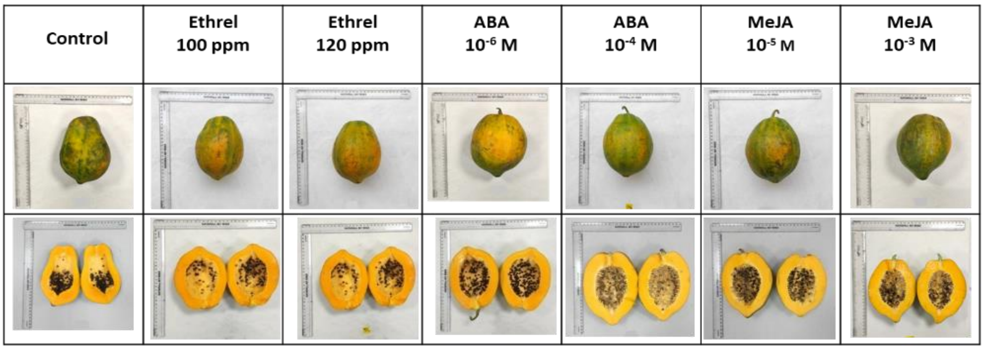


**Fig 1:** Effect of ethylene, ABA and MeJA on fruit peel and pulp colour in papaya var. Pusa Nanha (Photographs taken under natural light at 15:00 hours).

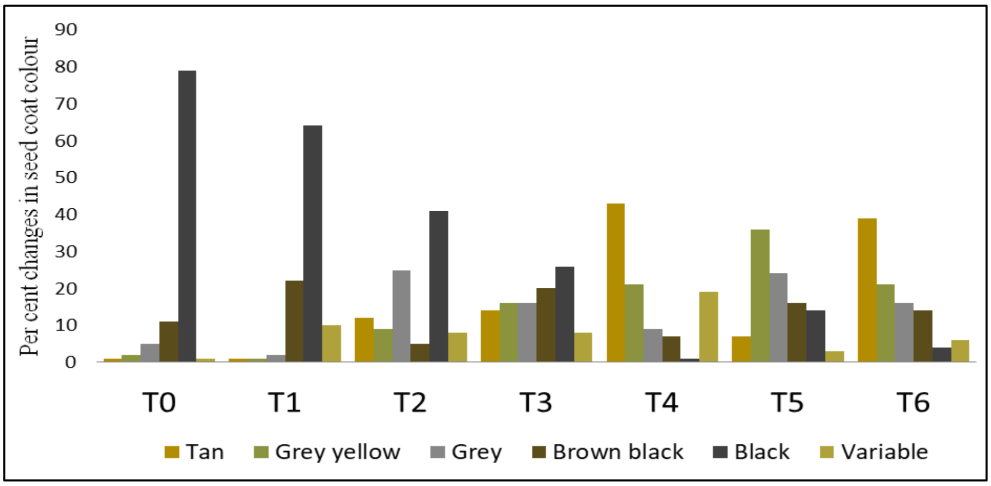


**Fig 2:** Effect of ethrel, ABA and MeJA on seed coat colour of ripened fruits in papaya var. Pusa Nanha.

## 4. Conclusion

From the present study, it is concluded that in North India when papaya var. Pusa Nanha cultivated under the protected cultivation and exogenously treated with 120 ppm ethrel was found to improve the peel and pulp colour, TSS, reducing sugars, total sugars, flavonoids, antioxidant activity and lycopene content of fruits, while fruit, early ripening, total phenols, ascorbic acid, total carotenoids and β-carotene content were enhanced with the application of $10^{-5}$ M MeJA.

## 5. Authors' contribution

Conceptualization of research (KS, JP); Designing of the experiments (JP, KS, BS); Contribution of experimental materials and Execution of field/lab experiments and data collection (BS, JP); Analysis of data and interpretation (KS, SKS); Preparation of the manuscript (BS, KS, SKS, VS, JP, VM).

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## 8. Conflicts of interest

Authors declare that no conflict of interest exists.

## 9. References


1. Aman F, Masood S. How nutrition can help to fight against COVID-19 Pandemic. Pak. J Med. Sci. 2020;36:S121-23.
2. Bal JS, Singh MP, Minhas PPS, Bindra AS. Effect of ethephon on ripening and quality of papaya. Tropical Fruits. XXIII IHC 1990;296:119-122.
3. Dubey S, Sahu GD, Kumar V, Saxena RR, Hota D. Effect of plant growth regulators on chemical quality of papaya (*Carica papaya*) cv. Red Lady. Int. J Chem. Stud. 2020;2(8):197-99.
4. Fabi JP, Cordenunsi BR, de Mattos Barreto GP, Mercadante AZ, Lajolo FM, Oliveira do Nascimento JR. Papaya fruit ripening: response to ethylene and 1-methylcyclopropene (1-MCP). J Agric. Food Chem. 2007;55(15):6118-23.
5. Fan X, Mattheis JP, Fellman JK. A role for jasmonates in climacteric fruit ripening. Planta. 1998;204:444-49.
6. Gonzalez-Aguilar GA, Buta JG, Wang CY. Methyl jasmonate and modified atmosphere packaging (MAP) reduce decay and maintain postharvest quality of papaya 'Sunrise'. Postharvest Biol. Technol. 2003;28:361-370.
7. Greensill CV, Newman DS. An investigation into the determination of the maturity of pawpaws (*Carica papaya*) from NIR transmission spectra. J Near Infrared Spectrosc. 1999;7:109-16.
8. ICAR Databook. Indian Council of Agricultural Research, Krishi Bhavan, Dr. Rajendra Prasad Road, New Delhi-110001. India; 2019. p. 172. https://krishi.icar.gov.in/AgResDataBook.jsp.
9. Karaman S, Ozturk B, Genc N, Celik SM. Effect of pre-harvest application of methyl jasmonate on fruit quality of plum (*Prunus salicina* Lindell cv. "Fortune") at harvest and during cold storage J Food Process. Preserv. 2013;37:1049-59.
10. Lavanya K, Rao DB, Edukondalu L, Lakshmipathy R, Rao VS. Effect of post-harvest treatments on physico-chemical changes during ripening of papaya cv. Red Lady. Int. J Chem. Stud. 2020;2(8):1142-1148.
11. Liu L, Wei J, Zhang M, Zhang L, Li C, Wang Q. Ethylene independent induction of lycopene biosynthesis in tomato fruits by jasmonates. J Exp. Bot. 2012;63:5751-61.
12. Mattheis JP, Rudell DR, Buchanan DA. Ethylene intensifies but is not a requirement for methyl jasmonate-enhanced anthocyanin synthesis by 'Fuji' apple fruit. In XXVI International Horticultural Congress: Key Processes in the Growth and Cropping of Deciduous Fruit and Nut Trees. 2002;636:455-460.
13. Muengkaew R, Chaiprasart P, Warrington I. Changing of physio-chemical properties and color development of mango fruit sprayed with methyl jasmonate. Sci. Hortic. 2016;198:70-77.
14. Ozturk B, Yıldız K, Kucuker E. Effect of pre-harvest methyl jasmonate treatments on ethylene production, water soluble phenolic compounds and fruit quality of Japanese plums. J Sci. Food Agric. 2015;95:583-591.
15. Prakash J, Singh K, Goswami AK, Singh AK. Comparison of plant growth, yield, fruit quality and biotic stress incidence in papaya var. Pusa Nanha under polyhouse and open field conditions. Indian J Hortic. 2015;72:183-86.
16. Saniewski M, Czapski J, Nowacki J, Lange E. The effect of methyl jasmonate on ethylene and l-aminocyclopropane-1-carboxylic acid production in apple fruits. Biologia Plantarum. 1987;29:199-203.
17. Sheoran OP, Tonk DS, Kaushik LS, Hasija RC, Pannu RS. Statistical Software Package for Agricultural Research Workers. Recent advances in information theory, statistics and computer applications by DS Hooda and RC Hasija Department of Mathematics Statistics, CCS HAU, Hisar; c1998. p. 139-143.
18. Singh R, Dwivedi UN. Effect of ethrel and 1-methylcyclopropene (1-MCP) on antioxidants in mango (*Mangifera indica* var. Dashehari) during fruit ripening. Food Chem. 2008;111(4):951-956.
19. Wang YW, Malladi A, Doyle JW, Scherm H, Nambeesan SU. The effect of ethephon, abscisic acid and methyl jasmonate on fruit ripening in rabbiteye blueberry (*Vaccinium virgatum*). Horticulturae. 2018;4(3):24.
20. Zaharah SS, Singh Z, Symons GM, Reid JB. Role of brassinosteroids, ethylene, abscisic acid and indole-3-acetic acid in mango fruit ripening. J Plant Growth Regul. 2012;31(3):363-72.